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HIGH ALTITUDE RADIO RELAY SYSTEMS

FINAL REPORT

BY

D. FALES III

AND

STAFF

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ECOM

UNITED STATES ARMY ELECTRONICS COMMAND FORT MONMOUTH, N.J.

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Prepared by

David Fales III and Staff

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ABSTRACT

This is the final report on work performed under the High Altitude Radio Relay (HARR) study contract. The HARR program was an applied research study effort in support of the Advanced Research Projects Agency requirements for Remote Area Conflict communications (Project AGILE). The theoretical and analytical investigations were aimed at determining the key characteristics and parameters of systems to enable the use of military communications equipment over difficult paths.

The operational parameters considered were traffic, transmission range, terrain, foliage, frequency range, modulation, and types of relay capabilities. Equipment parameters were: relay control, transmission modes, size and weight, radio frequency power levels, receiver sensitivities, power requirements, operational life, interference, jamming, platform performance, platform payloads, compatibility, basing, availability, and costs.

The study was broken into four tasks: communication mission requirements, propagation analysis, relay analysis, and platform analysis.

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SECTION 1

SUMMARY AND CONCLUSIONS

1.1 GENERAL

This is the final report on work performed under the High Altitude Radio Relay (HARR) study contract. The HARR program is an applied research effort in support of the Advanced Research Projects Agency requirement for Remote Area Conflict communications (Project AGILE), and under the contractual and technical direction of the United States Army Electronics Command (USAECOM), Fort Monmouth, New Jersey.

The study is an investigation of elevated radio relays to extend the range of remote area communications. The systems considered can generally be separated into two parts; the electronics equipment, and the elevated support or platform.

1.2 OBJECTIVES

The objectives of the study are to select and recommend optimum relay equipment and compatible platforms from the current military inventory for the immediate time frame, and to recommend developmental areas for retransmission systems of the future.

1.3 SCOPE OF WORK

In identifying the optimum relay platform configurations, the study has been largely parametric and considers three time frames, initial (1968), interim (1969-1975), and long range (post-1975). For the initial period, investigation has been confined to the use of existing inventory equipment. Recommendations for the interim time frame include improvement to existing equipment. For the post-1975 period, promising areas for development and applied research are discussed.

1.3.1 Approach. The requirements for rebroadcast systems in remote area conflict have been examined mainly in the context of war in Southeast Asia. Section 2 of this report is an overview of communications in Viet Nam. It discusses the military organization, geography and climate, tactical concepts, and communication systems. Section 3 discusses the principles of relay operation, wave propagation over difficult paths, application of contemporary equipment to the retransmission problem, and the potential for relay development. The examination of platforms in Section 4 includes a selection analysis, cost effectiveness modeling, and a random aircraft sortie distribution analysis. A variety of elevated platforms are discussed including powered aircraft, manned and unmanned, a tree-supported platform, and tethered and free balloons.

1.4 CONCLUSIONS AND COMMENTS

In addition to the specific recommendations for equipment, usage, development, etc., contained in the body of this report, some general comments and conclusions may be drawn from this study.

A. No single platform/relay combination can be specified as optimum for all purposes. The requirements are a function of the mission, logistics, tactical exigencies, etc.

B. The use of combinations of existing communications gear for high altitude relay in the F1-F2 mode may be difficult unless the equipment was specifically designed for the purpose. The spurious radiations and responses of conventional transmitters and receivers are typically required to be at least 50-70db below performance at the channel frequency. This is insufficient for relay operation where the necessary margin may exceed 150-170db. Tests of the AN/PRC-25 transceiver described in the appendix clearly illustrate this problem.

C. The conclusion of B may be extended to suggest that multiple channel high altitude relay using inventory equipment not designed for the purpose may be difficult or impossible, especially in the VHF region.

D. Platform costs for HARR so exceed the relay equipment expenses that the cost analysis for the platform alone is essentially the same as for the platform/relay combination. Thus, a 100% increase in relay cost to produce 10% better mission performance may be an economy.

E. Development of directive antennas, even at VHF, is considered a necessity for HARR if their potential is to be developed. In the absence of antenna directivity, long range RFI problems will limit the number of elevated relays that the spectrum will accommodate.

F. The concept of high altitude switchboards similar to dial-direct radio telephone systems should be explored. An elevated switchboard would provide a higher utility factor for the available channels than a repeater. Better utilization of channels becomes a necessity for a tactical network, for instance, where a large number of users make infrequent calls of short duration.

SECTION 2

COMMUNICATIONS REQUIREMENTS AND MISSION MODELING

2.1 INTRODUCTION

The objective of this program is to study airborne relay systems which will extend military communications in remote areas of conflict.

A study of airborne retransmission to extend communications must include a definition of "how far" and "by what means" since the Signal Corps has a variety of equipment in inventory which might be used for the purpose. An assessment is made of these inventories, both present and proposed to consider them in the light of their parametric tradeoffs. The question of "how far" must be controlled by interference considerations and constrained by distance requirements within a tactical operation. In addition to the problems of spectrum conservation, it should be noted that all communication schemes must, for the present, be compatible with existing equipments. Technological quantum jumps such as RADA, adaptive signalling, RACEP or digitized voice systems which promise conservation in RF spectrum must initially operate with existing equipment and frequency assignments.

In accordance with the Technical Guidelines, the upper limit for range extension by radio relay is 300 miles. This would include communications in command echelons as high as field army level. This figure, therefore, requires or permits this study to evaluate all military communications in Vietnam.

The role of military communications in Viet Nam has been expanding and several military systems now serve both military and civilian populations.

The study of airborne relays should, therefore, include methods to support both tactical and civilian populations in reacting against enemy terrorism and disruption of government. In support of this hypothesis is the recent U. S. decision to place the passification program under military control. It is supported by a "hamlet" radio system to provide rural area communications.

A third aspect of this study is the effect of geography on communications in counter-insurgency warfare. The study is directed at difficult terrain and transmission anomalies in dense tropical jungle and/or mountainous regions. The objectives are to determine tactical and operational characteristics peculiar to each region.

Communications has assumed such an important support role on the battlefield that it would be interesting to consider the ways in which tactics might be modified through improved use of airborne relays. It should be noted here, however, that this study is not intended to evolve tactical concepts, but rather to examine the communication ingredients common to effective command and control and to investigate means by which these ingredients may be improved.

The study is directed at both forward and rear area communications. The forward areas relate particularly to manpack and vehicular equipment, while semifixed and fixed plant terminals are appropriate to the rear echelons.

2.2 SCOPE

This study program investigates how airborne radio relays can improve military communications in remote geographic areas. Improved communications could logically result in radically new methods of tactical deployment. Such a metamorphosis in tactics has resulted from the introduction of airborne command posts; their success in Viet Nam has prompted the organization of an air-mobile division, the first of its kind in the United States.

Although the term, "military," implies all services, this study is concentrated on the ground combat efforts of the U. S. Army with only peripheral attention to the Air Force and Navy tactical air support and airlift. Marine Corps fighting units are considered in the same context as Army elements.

2.3 THE TACTICAL MILITARY COMMUNITY

2.3.1 Organizational Structure. Until recently, the major elements within the U. S. Army, i.e., field army, corps, division and brigade, reflected a rather rigid infrastructure of manpower and equipment. Aside from the flexibility of assignment permitted within the context of supporting or attached units, i.e., artillery, reconnaissance, engineering, signal, etc., maneuver within the field army was predicated upon a rigid divisional structure of three infantry regiments, (now called brigades) with three infantry battalions assigned to each regiment. The doctrine of "two-up and one in reserve" was reflected in a "triad" concept of tactical deployment and unit organization. Similarly, each battalion had three maneuver companies and each company had three maneuver platoons. For the most part these unit ratios still exist, with one exception: the infantry regiment has been replaced by a brigade with a flexible strength ranging from one to five infantry battalions.

More significant however, is the degree of tactical freedom permitted the small echelons of command. This degree of independent action has developed from the need for a force tailored to meet a variety of combat situations including counter-insurgency, police action, or a show of force.

The division is permitted internal tailoring to meet the tactical needs and the basic maneuver element is the battalion. Separate brigade and battalion size operations are consistent with this doctrine.

As a further extension of this philosophy, all tactical elements of the division have been relieved, to a large extent, of administrative and logistical responsibilities.

In consonance with the army's tactical doctrine of providing "flexible response," these units, divested of administrative and logistical burden, are capable of offensive or defensive deployment in wide areas. Unit decentralization and airlift capability permits the commitment of units several hundred miles distant in a matter of hours, creating the need for single and multiple channel command communications over these distances from portable and vehicular radio terminals via previously unestablished routes of communication.

The echelons of command embody the tailored force principle as outlined in the organization objectives of the field army for the 1970-1980 time frame. This field army would consist of from one to a maximum of three corps. Each corps could have from one to six divisions. In each division would be from one to three brigades, and each brigade could be assigned from one to five battalions. It can be seen from this that troop strength cannot be uniquely assessed as a function of these command echelons.

Similarly, because of the variety of independent missions which can be performed by battalion and smaller size units, it is neither desirable nor possible to infer deployment distances. In view of the extended troop lifts successfully undertaken in Viet Nam, it is safe to say that troop deployment to areas of opportunity would extend to any distance within the airlift range of available aircraft and the reliable communications range between the staging area and the tactical zone.

2.4 GENERAL TACTICAL CONCEPTS

Communications requirements and equipment emphasis has changed considerably over the past two decades. During World War II, the battlefield in Europe was one of total commitment and troop units were dispersed across the width and breadth of continents. Troop displacement was generally continuous along a front, and terrain once occupied or passed through was retained and held secure.

In contrast with the tactics and terrain of World War II is the war in Viet Nam. Unlike war on a major political and tactical scale, the battlefield there can more accurately be described as continuous in terms of the enemy with small pockets of friendly forces operating alone on missions of short duration. The war might be described as a battalion, company, and platoon leaders' war. Brigade-sized units, and often battalion-sized units, operate on search and destroy missions many miles from the friendly stable rear areas. Airlifted in by helicopter, these units move forward through enemy terrain, destroying small pockets of resistance, village terrorists and equipment depots; and once the friendly forces pass through and no longer occupy an area, it is likely to again become enemy territory. Combine this tactical dispersion with the dense tropical jungle or mountainous terrain and a situation prevails which taxes the range and performance of existing small unit radio equipments.

British fighting units experienced similar communications difficulties in the late 1950's as evidenced by documents describing the limitations which jungle conditions impose on radio communications as normally practiced in a tactical area.

Vegetation, terrain, and the heavy reliance placed on tactical radio communications have placed severe support demands upon the present generation of tactical radio sets.

Combat operations in remote areas of conflict utilize tactical units that are highly mobile and dispersed over broad areas of widely varying terrain. The degree to which such mobility and dispersion can effectively be attained will bear on the means to maintain command and control. The achievement of these means depends on the adequacy of communications.

2.4.1 Tactical Communications Extension Requirements. The ability to quickly deploy troops over large distances to areas of enemy concentration constitutes a major tactical advantage of the ARVN, U.S., and Free World Forces in Viet Nam. By the use of helicopters well supported by artillery and tactical air, commanders are able to achieve surprise and shock action. Such actions can generally be described as airmobile operations. It places long-range communications demands on existing VHF ground equipment and is presently employing airborne relay to a limited extent. The command elements in many airmobile tactical commitments utilize aerial command posts operating between the staging area and the landing zones (LZ) where helicopters discharge the troops into the combat area. Displacement distances vary considerably from 10 or 15 miles to 150 miles. Early operations of this type were limited to the range of supporting artillery; however, recent actions have provided for the airlift of artillery units thus permitting deeper penetration.

The present command and control practice is to place the commanders and observers aloft and includes typically three to five command elements. Radio nets are usually effected from this airborne command post to medical, fire support, armed and troop lift helicopters as well as with the units committed on the ground. Communications to the staging area, which is the longest distance requirement, usually employs VHF/AM/SSB means. Generally, the air-to-air and air-to-ground paths in the vicinity of ground fighting is VHF.

These missions typify the need for long-distance communications between the command elements of isolated fighting units and other supporting arms. The isolated unit may be as small as 20 to 30 men on a patrol mission committed for periods of several days, or it may be a brigade deployed into a province for sustained operations over two to four week periods.

2.5 GEOGRAPHY AND ITS EFFECT ON MILITARY TACTICS

2.5.1 Operations in the Central Highlands

2.5.1.1 General. The Central Highlands area constitutes almost 50 percent of the South Viet Nam land mass. It is a rugged, mountainous area with maximum elevation ranging from 4500 to 7000 feet in the vicinity of Dalat and from 3000 to 8000 feet in the area west of Quang Ngai. The area slopes steeply down to the coastal plain on the east and more gradually on the western plateau, resulting in a strong contrast between the short, swift, eastward flowing streams with their steep-walled, narrow valleys and the more sluggish westward-flowing streams with their broad flat valleys. All streams are swollen and difficult to ford during the rainy season. Operations in this area differ greatly from those in the Delta and coastal plains because of the differences in terrain, weather and population.

2.5.1.2 Terrain. Steep slopes, sharp crests and narrow valleys characterize the mountainous areas. Numerous razorback ridges run in all directions and it is virtually impossible to follow them in any one direction for more than a few hundred yards. The forested areas of the foothills up to 3000 feet have an unbroken continuity of tall trees that form a dense, closed canopy over the ground. The undergrowth is very thick, comprising an almost impenetrable mass of smaller trees less than 10 feet high, intermingled with thorny shrubs and vines. Most streams are bordered by high, steep rocky banks and are generally swift with rapids and shallows common. Fording is possible in many places except during the flash floods which occur during the rainy season.

2.5.1.3 Weather. In the highlands, the southwest monsoon season lasts from May to October. During this period low clouds and ground fog limits observation and seriously restrict aerial activity. Cloud ceilings are less than 3000 feet about 80% of the time. Average monthly rainfall is approximately 13 inches. The average high temperature is 88 degrees with an average low of 55 degrees.

2.5.1.4 Movement. The steep terrain and dense jungles reduce foot mobility. Rate of march is usually from one-half to two kilometers per hour with frequent rest stops. Experience shows that there is a tendency to overestimate the rate of advance of columns. The amount of rations and equipment carried by the individual soldier must be carefully considered to prolong his effectiveness.

Wheeled and track vehicles will be restricted to the existing roads and trails. Bridges in this region are not capable of supporting heavy loads.

The limited number of suitable landing zones requires careful and detailed reconnaissance in order to conduct heliborne operations. Open areas are sometimes covered with stakes and tree stumps, which may prohibit helicopter landings. The high altitude and small landing zones result in a reduction of helicopter lift capability.

2.5.1.5 Combat Support Considerations

a. Artillery. Limited road nets or complete absence of roads restricts movements of artillery. Suitable positions are difficult to find, and sometimes clearing and leveling is necessary prior to positioning artillery pieces by helicopter.

b. Air Support. Dense jungle, low clouds and ground fog restrict air support. The locations of friendly forward elements are frequently difficult to determine from the air, limiting the delivery of close supporting fires. Units should plan the use of pyrotechnics, panels and other devices to mark their forward positions.

2.5.2 Operations in Swampy and Inundated Areas. Operations in swampy and inundated areas in Viet Nam are generally associated with the Mekong Delta--that region of Viet Nam which lies south and west of the city of Saigon and is laced with rivers, streams, and canals. However, some of these conditions exist along the northern coastal plain in small delta areas. Rice paddies comprise most of the Delta. Two other types of areas within the Delta, the Plain of Reeds and the Mangrove Swamps, are treated separately below.

2.5.3 Rice Paddy Areas of the Delta

2.5.3.1 General. The rice paddy land of the Delta is the most heavily populated rural area in the Republic of Viet Nam; dwellings are found along nearly every waterway. Streams, canals and rivers interlace this area; trees and other vegetation along the waterways sometimes extend 300 meters on each side. The land between the waterways is covered by rice paddies, and during the rainy season these paddies are covered with water to a depth of one foot or more. In the dry season these same rice paddies dry up and crack open.

2.5.3.2 Movement

a. Routes. There is an extensive network of rivers and canals usable throughout the year, and generally capable of supporting craft as large as landing craft, mechanized (LCM). River craft are confined to the major canals and to the rivers. Overhead bridge clearance and depth of water at high and low tide must be considered in planning use of river boats. Assault boats can operate freely on minor canals only during high tide. Native sampans operate at all times.

b. Ground Troops. Troops can maneuver in the paddies on foot the year-round. Foot movement during the dry season averages three to four kilometers per hour during the day and one and one-half kilometers per hour at night. During the wet season foot movement may be slowed by difficulties in crossing canals; a combination of deep water and steep muddy banks may result in insufficient traction. Consideration of the tide is necessary, even far inland, as high tide favors boat movement, while low tide favors wading across canals in most search operations. Several large-scale operation have failed or have been aborted because the effects of the tide were not considered.

c. Helicopters. Most rice paddies in both the wet and dry season are potential landing or loading zones.

d. Airborne Troops. Airborne forces can be employed year-round with few limitations on the size of the force dropped. During the wet season the water depth of the rice paddies should be considered when selecting drop zones. If the situation requires it, drop zones can be successfully selected immediately prior to the drop.

2.5.4 Plains of Reeds Area of Delta

2.5.4.1 General. The sparse population is scattered throughout the small hamlets at canal or stream junctions and along the banks of these waterways. During the rainy season when the entire area is inundated, the people live in elevated houses or in sampans. Even during the dry season, the area is continuously covered with water varying from ankle to shoulder depth and blanketed by reeds and grass one-half to four and a half meters high. There are trees scattered along the small number of canals and streams in the area. During the dry season many parts of the area resemble the midwest prairies from the air. In the wet season it looks like a sea or large lake.

2.5.4.2 Movement

a. Routes. There are only two major canals and a single road across the area. Inhabitants normally travel by boat and sampan, often directly across flooded fields.

b. Ground Troops. The average rate of travel cross-country by foot in the dry season is 1.5 kilometers per hour. During the wet season foot travel seldom exceeds one kilometer per hour and in many places is not possible at all. Armored personnel carriers are most valuable in this area, although frequent stops are necessary to cut the reeds and grass from the tracks and drive sprockets. River force craft are limited to larger streams and canals. They are sometimes used to carry troops to the general area of operations but can seldom be utilized to support an assault operation.

c. Helicopters. Helicopter landing zones in the Plain of Reeds are limited. In the dry season, canal and river banks may be used for landings, but in the rainy season troops must be loaded and unloaded from hovering helicopters. Care must be taken not to offload troops in water reaching over their heads. Small boats can be lashed to the skids of helicopters and used to disembark troops.

d. Airborne Troops. Airborne troops can be employed effectively throughout most of the area depending upon the depth of the water and the season of the year.

2.5.4.3 Combat or Fire Support. Moving artillery into position to support operations requires boat or helicopter transportation and usually compromises security. Heavy mortars and artillery which can be delivered by helicopter still possess the disadvantage of limited range for the usually large-area operations conducted in the Plain of Reeds. Naval guns can support operations within range of the Mekong River. Tactical air support and armed helicopter support are most useful. Assault boats or sampans may be used to carry heavier crew-served weapons and ammunition.

2.5.5 Mangrove Swamp Area of Delta

2.5.5.1 General. Population is very sparse and is concentrated along the shore line or at river and stream junctions. Most houses are built on stilts because of the wide variations of the tides. Few people actually live in the swamps. Trees, vines, exposed roots and dense undergrowth are marks of the Mangrove Swamps. Swamp depths, depending on the tide, vary from one meter of mud to one meter of mud covered by two meters of water. Tides cause river current to reverse direction as the tide changes.

2.5.5.2 Movement

a. Routes. There are no roads in the Mangrove Swamps. Boats traveling into the area during high tide can be stranded at low tide and may have difficulty reaching shore. Sampans can enter the area from the sea only during high tide. Although these conditions hamper tactical troop landings, several successful landings have been made. LCM's and LCVP's can get close to shore only by following river channels.

b. Ground Troops. Foot movement is very slow. The average rate of foot movement is one kilometer per hour, and may be only a few hundred meters per hour. Armored personnel carriers can operate in only a few parts of the Mangrove Swamps, generally around the edges. Sampans and SSB's are limited to the few streams and are likely to be stranded at low tide.

c. Helicopters and Airborne Troops. Helicopter and airborne forces can be employed in mass only on the fringe areas of the Mangrove Swamps.

2.5.5.3 Combat or Fire Support. The planning considerations for the use of artillery, mortar and air support are similar to those necessary for operations in the Plain of Reeds. Naval gunfire can be used. Consideration should be given to the use of assault boats or sampans to carry heavier crew-served weapons and ammunition.

2.6 COMMUNICATION SYSTEMS

2.6.1 Configurations. Military radio communications can be described as area, network, or point-to-point systems.

2.6.1.1 Area Systems. Area communications usually extend from Army rear to Division rear. They are largely common user circuits over which a variety of signal forms are transmitted. Multiple channels are principally used to link signal centers (see Figure 2-1). The signal centers or nodes within the resulting array perform manual or automatic switching and supervision functions on voice and teletype traffic in a manner similar to telephone central office procedure.

2.6.1.2 Tactical Networks. Tactical radio nets are typified by the structure shown in Figure 2-2. A net will consist of two or more transmitters and receivers operating on the same frequency. The operating mode is "push to talk"; that is, the transmitters are only activated when a person wishes to speak. For all other conditions, only the person's receivers are on. No more than one transmitter in a net can be active at any given time. In accordance with tactical echelons of command, the commander in one net is also a member of the next higher echelon net.

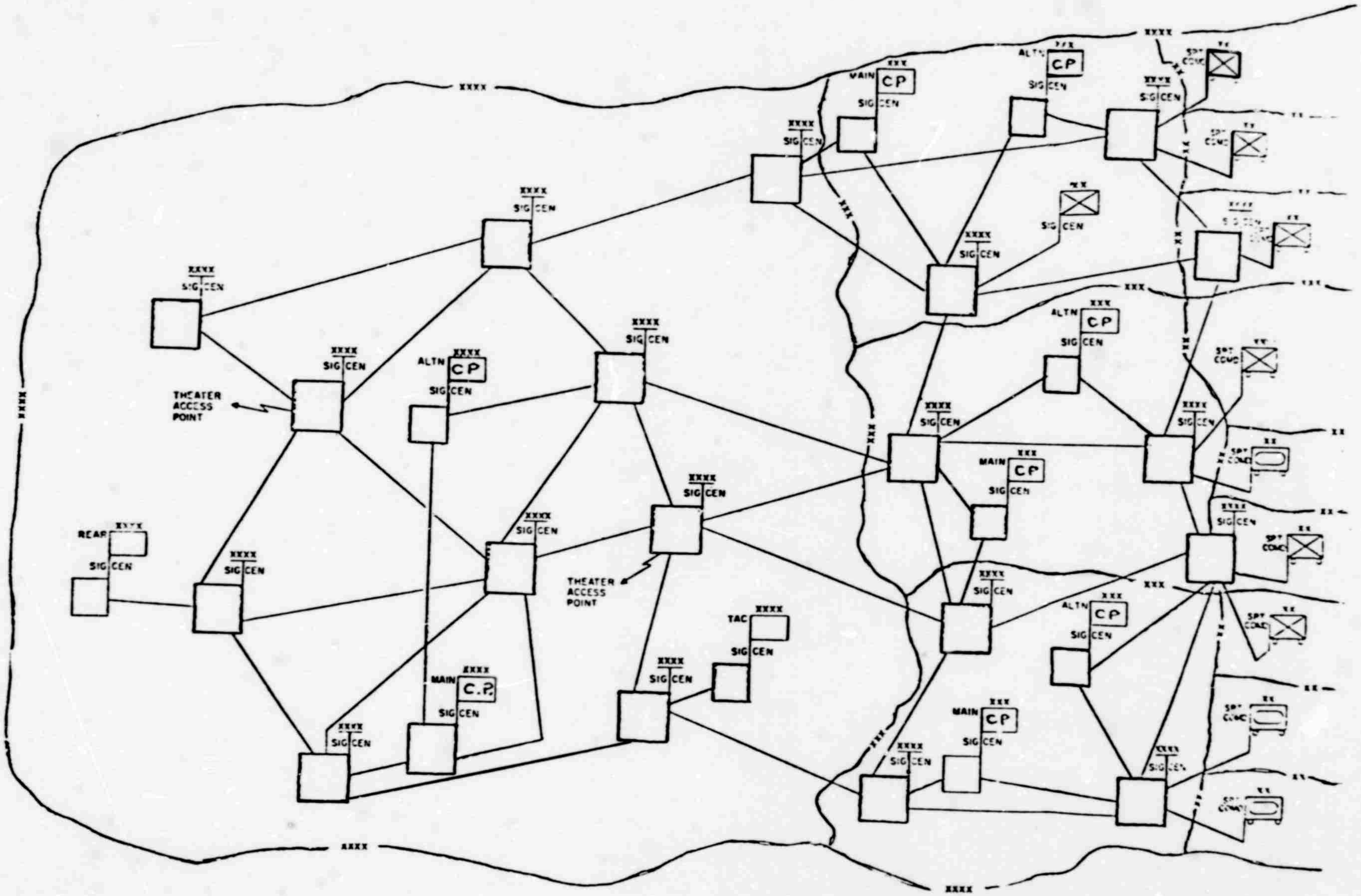

Figure 2-1. Army, Area Multi-Channel Communication System

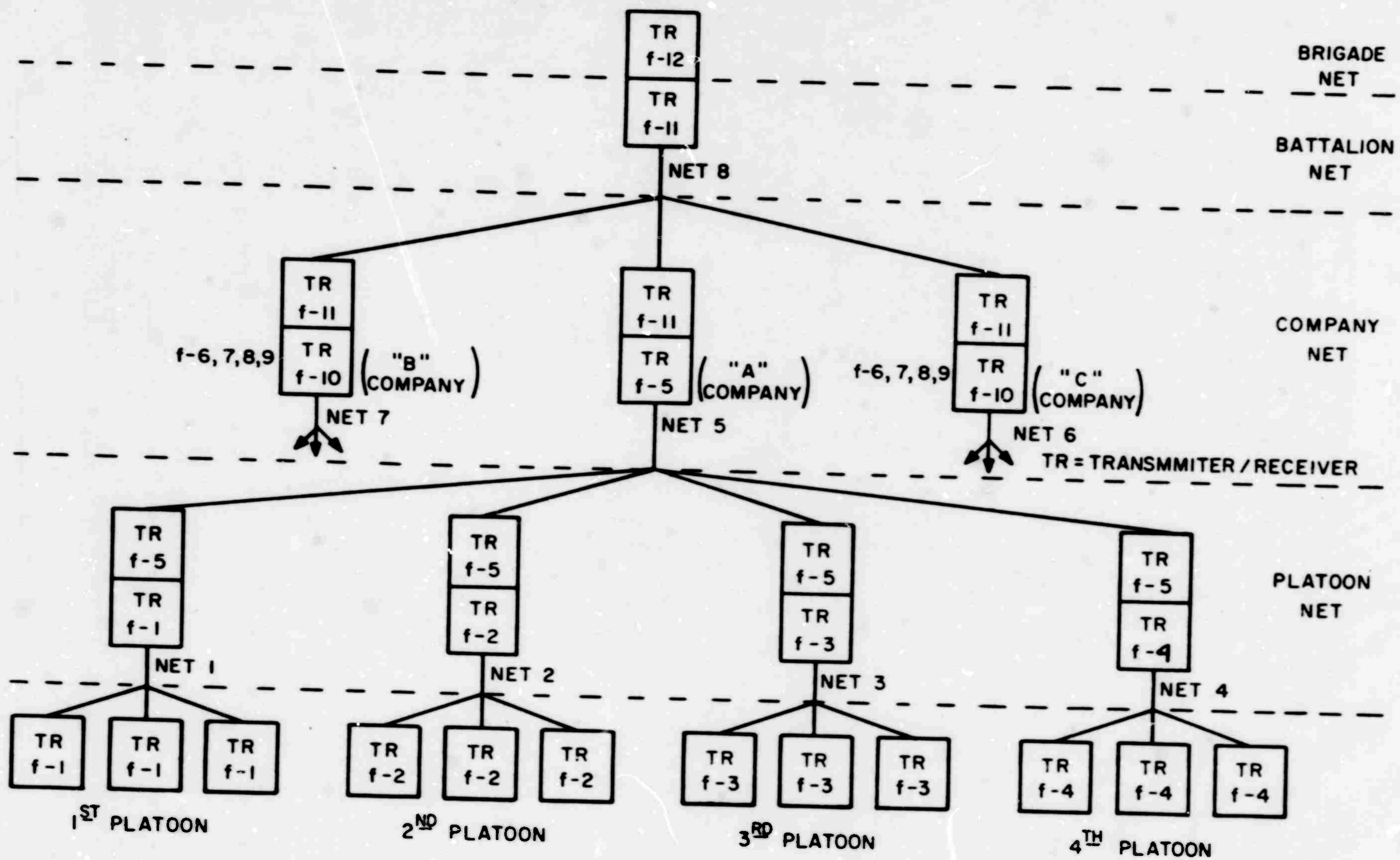

Figure 2-2. Typical Net Structure

Network systems permit quick exchange among all subscribers, random deployment, and a high degree of mobility. All of these are essential to division or smaller unit operations. The number of users in a network will depend on the number of common interest subscribers (i. e., logistics, intelligence, air traffic, etc.) subordinate to the next higher command level. The tactical chain of command provides that each successive command element occupy, in addition to its own net, a position in the next highest command net using a second radio terminal. This arrangement confines the subordinate network subscribers to the command boundaries. Within each net at division level and lower, one subscriber is usually appointed as net control station (NCS) for insuring good radio procedure, advising of radio silence, and establishing subscriber precedence during periods of high traffic. In the absence of automatic encryption, transmission security is usually effected through the use of prearranged phrases, code words, or recitation from classified authentication tables in the signal operating instructions (SOI).

Network systems will also be found above division level, however, they are used principally for teletype traffic in support of operations, air support, and/or logistics. The principles of operation are essentially the same as for the voice nets described above. The traffic is largely administrative, routine operational, or limited intelligence data. The subscribers in each net usually share a common support function, i.e., reconnaissance, logistics, air request, etc. In the case of large networks, a degree of formality (message address and sender identification) is required on the part of each subscriber.

2.6.1.3 Point-to-Point. Point-to-point systems sustain high traffic volume between two geographically fixed subscribers. Conventionally these systems are found at higher tactical echelons where terminal displacement is infrequent and directional arrays permit spectrum conservation. These links carry high priority operational traffic in record form between the army, corps, and division command levels as well as to adjacent army command posts. For this reason they are usually accomplished at VHF or microwave frequencies and do not pass through switched or repeater terminals.

Application of point-to-point systems at the lower command echelons is increasing in Viet Nam as the complexion of the war is permitting the smaller headquarters, airfields, supply depots and base camps to remain in fixed positions.

2.6.2 Unit Requirements. This section discusses the communication required to support the major elements of a field army. The links shown for each level of activity are consistent with the RODAC-70 field army concept.

Signal corps doctrine establishes responsibility for communication installation on a higher-to-lower and left-to-right basis. Each echelon shown in the following paragraphs includes links consistent with this doctrine.

2.6.2.1 Field Army. Field army communication is established in area, network, and point-to-point systems.

2.6.2.1.1 Area. Consists usually of 18-24 area type signal centers which provide signal facilities within designated geographical areas and serve all units within the area requiring such support. Area signal centers remain under the operational control of the signal officer of the command providing the area center. Internal communications of the supported units remains the responsibility of those units. The signal centers are usually arranged in a matrix interconnected by both multi-channel radio relay and cable links with total channel capacities between centers ranging from 24 - 96. The system matrix extends from the rear of the field army area through the combat zone and connects into the division communication system at the division rear boundary.

The Signal Centers provide telephone and teletypewriter switching, rerouting, radio wire integration, radio, radio relay and carrier transmission and reception. Each signal center provides all signal facilities required to support the units and activities within its assigned area of responsibility. The signal center of the field army area communication system is interconnected with at least two others to provide divided and alternate routing and permit distribution of the traffic loads.

As opposed to an axis form of communication support used in World War II and Korea, an area signal center may be destroyed without disrupting traffic. The field army area communication system is designed primarily as a common user system.

2.6.2.1.2 Network. Network radio-teletype systems include:

a. Links from main army Command Post (CP) to each corps CP.

b. Links from main army CP to each major tactical unit not attached to the corps.

c. Army Air Request links connecting main field army tactical operations center and each of the divisions attached to a corps. A separate net is established for each corps which is used for control of requested, immediate and pre-planned air strikes.

d. Logistical Nets are established between army rear CP and the support command of each division attached to the corps. As in 3 above, a separate net is established for each corps. Since corps headquarters is primarily a tactical organization, logistical requests from front line divisions bypass corps HQ and pass directly to the rear field army CP over these nets.

e. Army Air Information Nets connecting army main CP and each corps CP and the army reconnaisance support battalion (ARSB).

f. Army Ground Liaison Officer Nets established between army main CP and each tactical air force wing. Normally there are two tactical air force wings of four squadrons each in support of one field army. These nets are used to effect coordination of tactical air support.

g. Air Reconnaissance Liaison Net (ARLO NET) established between air reconnaissance support battalion and the liaison officers at each air force reconnaissance squadron, normally one wing with four squadrons in support of a field army. The net is used to pass intelligence traffic to the support battalion where it is processed and passed on to army and corps CP's, over the air information net.

2.6.2.1.3 Point-to-Point. Point-to-point systems include links for both voice and teletype. One voice link is the Command Multi-Channel facility. This system provides command and control to highly mobile elements and is independent of the area-type system. It consists largely of point-to-point multi-channel links between the following elements:

a. Army main command post (CP) to each corps CP (24 channels).

b. Army main CP to army advance CP (24 channels).

c. Army main CP to army group (48 channels).

d. Army main CP to army rear CP (48 channels).

e. Advanced logistics command CP to army rear CP (48 channels).

f. Army main CP to air defense headquarters (12 channels).

A second type of voice link is devoted to Air Defense. It has essentially the same requirements as the command multi-channel system. It connects air defense headquarters with air defense groups and air defense groups with their battalions and firing units. The links are usually 12 channel with ranges varying from 75-150 miles.

Teletype point-to-point links connect a field army main CP left and right with adjacent army CP's also with army group, army advanced and rear CP's. They also connect army rear CP with the Advanced Logistics Command (ADLOG)

2.6.2.2 Corps. The corps headquarters directs the tactical functions. Primary emphasis is placed on the support of tactical operations and intelligence traffic through point-to-point and network systems. As in the field army command post, there is little requirement for vehicular or manpack communication. The field army system is used as backup to carry administrative and logistical traffic.

2.6.2.2.1 Point-to-Point. The point-to-point systems link Corps Command and Corps Artillery. Corps Command communications consist of 24-channel secure links between the main corps command post and each of the following command posts:

a. Corps advance
b. Each division
c. Corps artillery
d. Mechanized brigade
e. Armored cavalry
f. Aviation group
g. Military intelligence battalion

Corps Artillery Command links provide close and continuous control of all corps artillery support fire unit command posts. These systems connect corps main CP with:

a. Division artillery
b. Target acquisition battalion
c. Each artillery group
d. Air defense artillery group

Each link has a 12 channel secure capacity. The links are terminated directly at the command elements and generally do not pass through switched or repeater terminals.

2.6.2.2.2 Network. Network systems consist of secure, 600 wpm, of teletype traffic between:

a. Corps CP and each division CP
b. Intra-Corps Command Posts; i.e., rear, main, advanced and adjacent corps
c. Between the corps, mech. brigade, engineer brigade, and armored cavalry command posts
d. Between the reconnaissance collection agencies, the main and advanced corps command posts, the aviation group and the armored cavalry brigade command post.

2.6.2.3 Division. There are four types of army divisions, the infantry, armor, mechanized, and airborne. Communications requirements are similar for each.

Communications within the division places heavy reliance on vehicular forms of communication, makes extensive use of voice network systems, and uses radio wire integration between mobile VHF/FM and the division area telephone system.

Division communications are established in area and network configurations.

2.6.2.3.1 Area. The division area system is similar in concept to the army area system. An array of mobile signal centers are inter-connected by 12 channel vehicular mounted terminals.

2.6.2.3.2 Network. These links have both teletype and voice terminal equipments. The voice systems include a division command net, a division staff net, an air request net, and an air warning net. The teletype systems include an operations and intelligence net, an administrative and logistics net, and a support net.

2.6.2.3.2.1 Voice Networks

2.6.2.3.2.1.1 Division Command Net. This net usually embraces a large number of mobile subscribers and includes the Division Commander, Operations Officer, Armored Cavalry Commander, Artillery Commander, Engineer and Aviation Battalion Commander and the Operations Center.

2.6.2.3.2.1.2 Division Staff Net. Similar in structure to the command net and includes the General Staff G-1, G-2, G-3, and G-4 plus air intelligence officer, surgeon, chemical officer and division signal officer. It is best described as in administrative and logistics network.

2.6.2.3.2.1.3 Air Request Net. Has the following prime subscribers:

a. Fire support control center
b. Armored cavalry squadron
c. Each brigade command post
d. Each maneuver battalion command post

The net is used to request and coordinate immediate or preplanned air strikes. The fire support control center terminal acts as net control station. Requests approved at division level are transmitted to Army level over the Army Air request net.

2.6.2.3.2.1.4 Air Warning Net. This is a one way voice network from either the division or division alternate command post to all subordinate units.

2.6.2.3.2.2 Teletype Systems. Teletype nets are used principally to afford greater range and record copy. Secure transmission is required.

2.6.2.3.2.2.1 Operations and Intelligence Net. This net includes the division main, advance, and alternate command post, division artillery, each brigade command post and the armored cavalry squadron command post. This net handles critical tactical and intelligence traffic, requires secure transmission and minimum 50 mile range.

2.6.2.3.2.2.2 Administrative and Logistical Net. Carries traffic similar to the division staff net among the division support command battalion, division artillery, and motor convoy operations.

2.6.2.3.2.2.3 Support Net. A general purpose net for operations, intelligence, logistics and administrative traffic among units located to the rear of the combat units. The subscribers are division rear command post, division support command post, each division area signal center, the surveillance platoon, aviation battalion, and engineer battalion.

2.6.2.4 Brigade. The Brigade communication system is dependent on VHF/FM, HF/Teletype, and HF/SSB radio equipment. Brigade command elements communicate with division solely by radio. Communications systems consist of voice or teletype networks. The voice links include command nets, administrative/logistical nets, intelligence nets and artillery battalion nets. There is one teletype net which carries principally logistical traffic.

2.6.2.4.1 Command Net. Includes the brigade commander, executive officer, intelligence officer (S-2), operations officer (S-3), air operations officer, supply officer (S-4), each battalion commander and each attached supporting unit commander.

2.6.2.4.2 Administrative/Logistics Net. Used to control supply, personnel and administrative matters and includes brigade elements plus battalion executive officer.

2.6.2.4.3 Intelligence Net. Conveys intelligence information relating to the enemy situation between the intelligence officers of each battalion and the brigade intelligence officer.

2.6.2.4.4 Artillery Battalion Support Net. This system consists of battalion headquarters, one forward observer for each infantry company, one liaison officer for each battalion and one liaison officer at the brigade command post.

2.6.2.4.5 Brigade Teletype Net. This net serves logistical elements which include the brigade headquarters, maneuver battalion headquarters and brigade convoy operations.

2.6.3 Frequency Management Considerations. In attempting to determine small unit radio requirements hence platform loads and relay packages, efforts to affix channel requirements to corresponding unit strength on the basis of classical tactical net structures results in a large concentration of channel frequencies in a relatively small area.

Consider Figure 2-1 which is typical of the frequencies found within an infantry rifle company. Typical distances between the internal elements of command within a rifle company are likely to range from 0.5 to 8 kilometers. On the basis of typical company frontages, units displaced laterally along the forward edge of a battle area would permit the reassignment of identical blocks of frequencies in every second or third company sector. Such is generally the case and is a distinct advantage in the application of VHF tactical radio sets on the small unit level (see Figure 2-3).

Figure 2-3 is an extension of the netting principle shown in Figure 2-1 as applied to an infantry brigade. For purposes of discussion and clarity, only the FM voice nets occupying the 30-76 MHz spectrum are shown. Considering normal areas of battalion occupancy or approximately a rectangle three miles wide and two miles deep, there would exist no less than 43 separate nets utilizing 23 separate frequencies. If no frequency sharing were permitted at the platoon and company levels, then 43 separate frequencies would be required.

Extrapolating these figures to a brigade comprised of three battalions and assuming frequency sharing as a function of range attenuation as in the first case above, then only one additional frequency would be required--the battalion/company command net. If no sharing were permitted, 20 additional frequencies or an aggregate of 63 would be required for a brigade made up of three battalions.

Concentrations to this extent are permitted in routine operations characterized by non-restrictive channel availability and terrain wherein there exists no large scale efforts to extend the design range of radio equipment.

Spurious signal or "on-site" interference does occur in such situations with the manpack and vehicular equipments when command elements employing these sets are co-located no more than several yards apart.* This frequently happens and is reported to be a problem in Viet Nam. Frequency selection in accordance with the interference charts that accompany the radio sets' appropriate TM would help alleviate this problem to some extent; however, the geographically random location likely with tactical sets and the limited channel availability estimated at 460 (30-70 MHz) does not permit

*See Appendix on PRC-25 tests

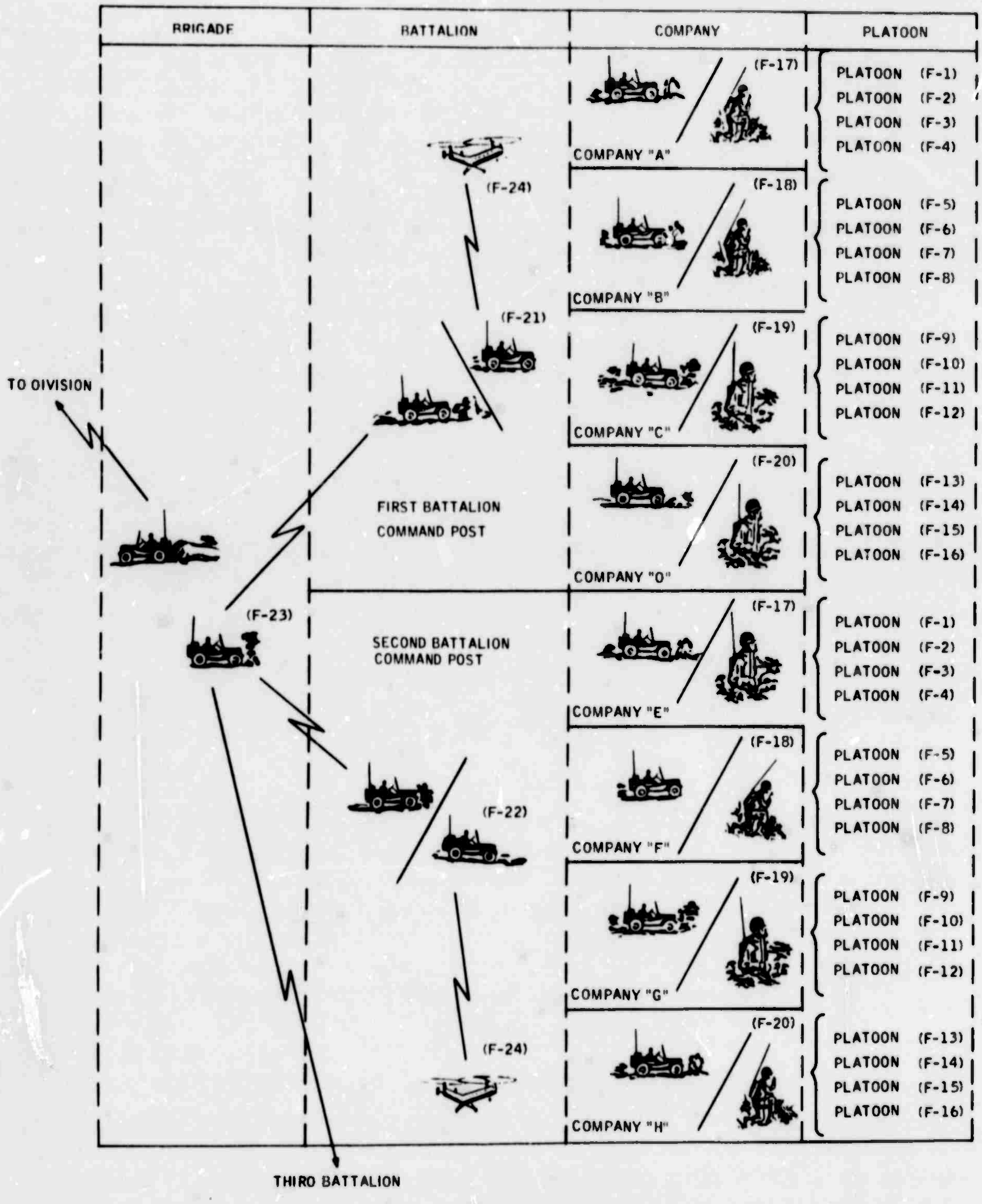

Figure 2-3. An Example of Typical Brigade Voice Radio Netting

exclusive interference-free geographical assignments. In view of the large number of users and limited availability of channels, optimization of channel assignment appears to be the only means by which interference can be reduced. As is often the case, however, time and a constantly changing tactical environment does not permit a statistical and probabilistic approach to these assignments at the small unit command levels.

Far site or co-channel interference resulting from the increased use of airborne command posts and airborne radio relay has been described* as a second area of concern to Viet Nam frequency coordinators. It is being used principally by the U.S. and Free World Forces as opposed to the Vietnamese. Relay support often takes the form of merely relaying a command message between two ground units experiencing difficulty.

There are also difficulties arising from the increased reception of numerous ground terminals by airborne receivers. Units have reported that large portions of a corps area appear on airborne command nets. The present means to combat the problem appears to be exclusive frequency assignment (FM-VHF) from airborne command posts to battalion level units.

The preceding illustrates the need for judicious application of relay schemes into the present communications structure in Viet Nam.

The limiting constraints and considerations include:

a. Tactical FM frequencies (VHF) are reported to be allocated in the following manner:*

<u>Vietnamese</u>

1. 27.0-54.9 MHz or 270 channels of 100 KHz spacing. The Vietnamese are not presently using equipment with 50 KHz channel spacing.

<u>U.S. and Free World Forces</u>

1. 20-26.9 MHz or 138 channels of 50 KHz spacing. This band is used principally by armored units.
2. 55-75.95 MHz or 418 channels of 50 KHz spacing. Approximately 120 of these channels (69.9-75.9 MHz) are committed to radio relay transmission (airborne or other means).
3. 84 additional channels between 27.0-54.9 MHz have been obtained from the Vietnamese spectrum and are allocated by the Military Assistance Command--Viet Nam (MAC-V).

*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam," Booz-Allen Applied Research, September, 1966.

b. Strict regard for platform height and power output to limit interference with allocation schemes based upon range limitation.

Table 2-1 reflects typical MAC-V assignments of the channels within the four corps areas.

It is assumed that the assignments in the 30-54.9 MHz region were made using only the 84 channels obtained from the Republic of Viet Nam Armed Forces and clearly illustrates frequency duplication or sharing on a non-interfering basis within each corps area.

2.6.4 Recapitulation. Figure 2-4 is a recapitulation of the above and shows the principal means of communications employed on an inter-unit basis in support of the fundamental command elements. Intra-unit communications, main alternate, advanced, and adjacent command post means are not shown for simplicity.

It can be seen that area, network, and point-to-point systems support the army to corps echelons in predominantly record form (TTY or data). The same is true between corps and division, however, fewer alternate means exist in support of a given command element. Network voice and teletype becomes the predominant means between division and brigade while network voice becomes the principal means at brigade and below.

2.6.5 Comparison of Area and Network Systems. Section 2.6 offers a brief examination of the communications support envisaged in the ROAD and RODAC-70 concepts. Application in Viet Nam and maneuver assessment in this country (operations "Swiftstrike," "We Will," and others) provide insight into problem areas in need of improved equipment or application.

These include the following:

a. The area or grid system of communications is difficult to achieve in areas continuously vulnerable to attack as in Viet Nam. It is equally difficult to achieve in other than rolling or average terrain. It requires an expenditure of combat troops for security and protection since the power generating and antenna equipment permit easy enemy detection.

b. Manual inter-nodal switching is cumbersome and inefficient involving excessive operator time and affords little user confidence. Automatic switching equipment capable of sustaining battlefield abuse is not yet a reality.

c. The area system has not been totally responsive to the communications needs of large numbers of widely dispersed and independent combat units or task forces. It would appear that airborne relay might (1) provide air to air trunking to reduce the number of ground based signal centers or relay nodes;

Table 2-1.* Number of Frequencies (30-70 MHz) Assigned Within the Four Corps Areas of Viet Nam (Maximum Power Not to Exceed 25 Watts)

MHz	I	II	III	IV	Total
30 - 31	2	2	2	2	8
31 - 32	11	11	11	11	44
32 - 33	23	23	23	23	92
33 - 34	9	8	8	8	33
34 - 35	15	11	12	11	49
35 - 36	15	7	11	14	47
36 - 37	4	4	8	13	29
37 - 38	17	17	19	23	76
38 - 39	33	19	19	19	90
39 - 40	36	17	24	22	99
40 - 41	26	1	11	8	46
41 - 42	13	2	10	4	29
42 - 43	20	2	7	6	35
43 - 44	26	2	11	9	48
44 - 45	25	1	12	7	45
45 - 46	20	3	12	11	46
46 - 47	17	4	14	9	44
47 - 48	18	12	8	-	38
48 - 49	15	9	6	-	30
49 - 50	13	-	5	-	18
50 - 51	16	2	6	-	24
51 - 52	16	9	6	-	31
52 - 53	11	10	6	-	27
53 - 54	11	10	6	-	27
54 - 55	7	10	4	-	21
55 - 56	11	-	3	3	17
56 - 57	5	1	1	4	11
57 - 58	8	1	1	5	15
58 - 59	5	1	1	5	12
59 - 60	-	-	-	4	4
60 - 61	-	-	-	3	3
61 - 62	1	1	1	4	7
62 - 63	1	1	1	5	8
63 - 64	-	-	-	1	1
64 - 65	1	1	1	1	4
65 - 66	-	-	-	-	0
66 - 67	1	1	1	1	4
67 - 68	1	-	-	-	1
68 - 69	2	-	-	2	4
69 - 70	-	-	-	-	0

*"The Management and Use of Tactical Radio Frequencies in the Republic of Viet Nam (Extracts from Military Assistance Command--Viet Nam J-6 Records)," Booz-Allen Applied Research, September, 1966.

Command-Element	Army to Corps		Corps to Division		Division to Brigade		Brigade to Battalion		Battalion to Company	
	Voice	TTY	Voice	TTY	Voice	TTY	Voice	TTY	Voice	TTY
Operations	P	PN	P	N	N	-	N	-	N	-
Intelligence	-	N	-	N	-	N	N	-	N	-
Fire Support	P (voice and data)		P (voice and data)		N (voice and data)		N	-	N	-
Logistics/Admin.	A	ANP	A	A	A	AN	N	-	N	-
Air Traffic	AP	NP	P	N	N	-	N	-	N	-

Legend
A - Area
N - Network
P - Point-to-Point

Figure 2-4. Principal Communications Means

(2) provide a more suitable and controlled environment for the automatic switching hardware, and (3) reduce the number of isolated, ground committed non-combatant signal support and security personnel.

d. Network voice and teletype systems best support the rapid and random troop displacement used to initiate effective offensive action against medium and high level counter-insurgency. Airborne relay may be ideally suited to providing area coverage (Ground-Air-Ground retransmission among many net subscribers) consistent with present convential application as high as corps level.

e. "Hamlet" or "village" radio networks constitute a vital defense against insurgent terrorism and propaganda. These nets established within political and geographic boundaries might also be served by airborne retransmission or broadcasting and define a support area limited only by national boundary.

Since airborne relay can effectively provide support in area systems and network systems, a numerical recapitulation of the three systems (area, network and point-to-point) is provided in Figure 2-5 which includes the accounting for individual multi-channel point-to-point requirements as multi-channel area links.

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Unit[1]	Networks (Single Channel) Voice	Teletype	Multi-Channel Area Links
Army (1)	None	30	48 channels - to each corps 24 channels - main to advance 48 channels - main to rear 48 channels - advanced logistics command to army rear 12 channels - main to air defense headquarters 12 channels - among air defense headquarters and air groups
Corps (3)	None	9 per corps see sec. 2.3.3.1.2 (b)	24 channels to each of 13 subordinate units (see section 2.3.3.1.2 (a)-1 corps command) from corps main C. P. 12 channels to each of 4 subordinate units (see section 2.3.3.1.2 (a)-2 from corps main C. P.
Division (6)	4 per division includes a one-way air warning net	3 per division	12 channels - to each brigade
Brigade (5)	4 per brigade	1 per brigade	None

1. The number in parenthesis is the total number of units that may be assigned the next highest command, i.e., 3 corps/army, 6 divisions/corps, etc.

Recap of Area, Network and Point-to-Point Systems

Figure 2-5.

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SECTION 3

RELAY SYSTEMS

3.1 RELAY ANALYSIS AND SELECTION

3.1.1 Objectives and Requirements

This section of the report pertains to the investigation and study effort performed to determine the characteristics and parameters required of the relay package to be carried by selected platforms.

The relay study task is grouped into sub-tasks as follows:

a. Propagation Path Loss
b. Relay System Identification and Tabulation
c. Parametric Evaluation of Selected Equipments
d. Recommendations for Relay Systems

3.1.1.1 Propagation Path Loss. The objective of this study area is to formulate a mathematical model of ground-to-air propagation which may be used to define relay coverage area and radio equipment specifications. This model was programmed for a digital computer, and parametric curves for path loss for representative terrain and foliage are included for use in analyzing the selected relay configurations.

3.1.1.2 Relay System Identification and Tabulation. Relay systems compatible with existing or proposed Field Army ground terminals meeting the requirements for relaying up to 48 voice channels are identified and their performance tabulated.

3.1.1.3 Parametric Evaluation of Selected Equipments. The relative performance of the equipment selected for relay use in the previous task is evaluated based on communications system requirements.

3.1.1.4 Recommendations for Relay Systems. Using the results of the previous task, a family of relay systems corresponding to the requirements is recommended. Where no existing system could be recommended for a particular requirement, recommendations for hardware development are made. Trade-off studies required to support these recommendations are performed.

3.1.2 Study Results

The paragraphs which follow describe briefly the results of the relay study effort.

3.1.2.1 Propagation Path Loss. An idealized mathematical model of jungle foliage effects has been combined with experimentally determined jungle electrical parameters.

Parametric curves of ground-to-air path loss are presented for various values of jungle physical and electrical characteristics. Variability data are used to estimate margin requirements. The path loss predictions and variability data are combined to predict the service range of particular relay configurations.

3.1.2.2 Relay System Identification and Tabulation. The characteristics of military and commercial radio equipment potentially capable of serving as high altitude relay components are examined and tabulated. This report contains tabulations and a review of relay system candidates for use in single or multiple channel applications.

3.1.2.3 Parametric Evaluation of Selected Equipments. In reviewing the tabulated data on existing radio equipment, suitable equipment has been found for meeting each of the relay applications requirements, although the systems require development effort in interfacing with the platform and with ground terminals.

3.1.2.4 Recommendations for Relay Systems. In the review of candidate systems for the relay functions, no completely satisfactory systems have been located for the requirements of channel capacity, range, ground equipment, and platform compatibility. Several configurations combining existing and readily developed equipment are recommended as the best solutions to the relay problem for the initial and interim time frames. Studies in particular areas of relay compatibility provide guidelines for recommendations for the long-range time frame.

3.1.3 Action Recommended

Preliminary recommendations may be made for the initial time frame relay systems and for specific work items beyond the scope of the present contract.

3.1.3.1 Tactical Network Relay. The continued use of the frequency translating relay configuration is recommended for the initial time frame. The low-speed switching common-frequency configuration may be developed relatively quickly, for the interim time frame, and offers somewhat greater compatibility with contemporary pack-set equipment. However, the desirability of digital modulation compatibility recommends frequency translation as a long-term technique, with appropriate adaptations of pack-set and vehicular radios.

The AN/ARC-114 is recommended as the basis of an interim time-frame relay at VHF, and the AN/ARC-97 at UHF. Both systems require limited interface electronics development.

3.1.3.2 Multichannel Relay. The use of a HARR type of radio relay (as distinguished from a satellite relay) for medium capacity multichannel links is feasible in the initial time frame using equipment designed specifically for ground-to-air relaying, the AN/ARC-89 (V). The use of such relay facilities may offer some useful advantages even after more widespread use of transportable satellite terminals is realized. Development of directional antennas insensitive to platform attitude is recommended for the interim to long-term time frames.

3.2 PRINCIPLES OF RELAY OPERATION

3.2.1 Relay Performance Requirements

3.2.1.1 General. In examining the performance requirements of the relay package, we will initially ignore the electronic mechanism of the relay itself, and treat the package as a "black box." Subsequent paragraphs will examine the feasibility of attaining the performance requirements with particular relay techniques.

3.2.1.2 Compatibility. The question of compatibility is closely related to the time frame constraints. The requirements for interface compatibility may be stated briefly as follows:

1. Initial Time Frame: Single "subscriber" access to the relay using VHF (30-76 MHz) FM transceivers, of which the AN/PRC-25 is typical.

2. Interim Time Frame: Single subscriber access to the relay using VHF (30-76 MHz) FM or UHF(225-400 MHz) AM. Field or depot modifications may be made to permit or improve relay-mode operation of transceivers. Multichannel relay may use inventoried transportable tropo low-level equipment or existing multichannel air to ground relay equipment.

3. Long Range Time Frame: Single subscriber access to the relay using optimal operating frequencies and modulation modes, but some areas of compatibility with earlier equipment may be required for communication with military units not equipped with relay-compatible equipment. Multichannel communication relay by satellite or by medium altitude platforms. Relay development should follow military objectives of conversion to digital modulation modes. RADA and anti-jamming provisions may be incorporated.

The other aspect of compatibility is that of compatibility with the electromagnetic environment. Interference generation by the relay-augmented network and susceptibility of the network to interference or jamming are important design criteria. Since the application of existing equipment is planned for the initial and interim time frames, the ground segment of the system will not be remarkably different from the current EMC status of ground to ground networks. The relay platform altitude, however, leads to greater area coverage of interference from the relay, and lowers the path loss from interfering signal sources. These effects may constrain the number of relay platform deployed and the number of channels which each relays for each of the time frames considered.

3.2.1.3 Range

The service range requirements established in Section 2 of this report must be interpreted in a probabalistic sense, since a fraction of the subscribers in a given area will not be able to communicate for one reason or another. Propagation variability due to foliage inhomogeneity, unfavorable antenna orientation or environment, and relay antenna pattern irregularities are some of the factors which contribute to unsuccessful communications. For this reason, a power margin allowance is made in the performance estimates to permit relay operation in approximately 99% of the locations within a given range. Conversely, the range corresponding to a given relay power, platform altitude, foliage effect, frequency, etc. is described in terms of the range for which there is a 99% probability of satisfactory communications service.

3.2.1.4 Number of Channels

It is apparent that not all of the FM networks will need relay augmentation. It is only when an occasional detachment becomes too far separated or enters foliage too dense for satisfactory communication that the relay is required. Further it is unlikely that all of the FM nets in the relay service area would need augmentation simultaneously. Therefore, there can be some sharing of backup channels and relay subsystems at the platform.

Since the use of the net with the emergency-only philosophy is based on relay operation only when direct communications fail, it is presumed that a relatively small number of relay channels would be required. The exact number if probably not too critical. The activity factor for a net is substantially less than 50% (5 "subscribers" each with 5% activity factors result in a net activity factor of 22.6%) and the probability of an unsatisfactory link in the net is probably less than 10%, so the probability of a particular FM net needing the relay would be less than 5%.

If a single net has a 5% probability of needing the relay, we may then compute from the binomial or Poisson distributions the number of relay channels required to accommodate the requirements of N nets for a particular fraction of the time. If this fraction (the probability of instantaneous availability of a relay channel) is 95% then for N = 10, 3 relay channels would be required[1], 4 for N = 20, 5 for N = 50, and 8 for N = 100. This is plotted in Figure 3-1.

The preceding argument has not included the delay in establishing circuits in computing the necessary number of channels. If the delay in completing circuits is comparable to the average message length, the fraction of useful time on a given channel will be reduced.

There may be some correlation in the usage of a number of separate FM nets, as military operations (on either side) may be synchronized in a number of areas, so the required number of channels may be larger than indicated above. The consequence of not having enough channels is that low priority calls may be delayed, but this is a relatively minor problem in comparison with a subscriber's having no communications at all.

3.2.1.5 Multiple Access

A basic requirement is that the repeater be available either full-time or on short notice to the net requiring its service. Since the cost of the relay platform is less per channel hour if it may carry a number of relay channels, it is expected that a number of nets will be provided with relay service by a single platform. As indicated in Paragraph 3.2.1.4 above, the number of relay channels may actually be somewhat less than the number of nets served.

There is a choice of autonomous control of the relay or supervised control. Autonomous control of access is compatible with unattended platforms, such as drones or balloons, but may require modification or augmentation of pack-sets to provide control functions. Otherwise, separate relay channels may be required for each network in the service area. Attended control requires a relay order-wire channel, on which the subscriber needing relay service would call the operator to request augmentation of his net. Attended control is applicable to either common frequency or frequency-translating relay systems.

3.2.1.6 Channel Quality

For the three time frames under consideration the basic channel quality requirement is that of intelligibility. The long-range time frame will also require suitable digital error rates and distributions.

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1. From a table of the cumulative terms of the binomial distribution (N=10, 20) or the cumulative Poisson distribution (N>20).

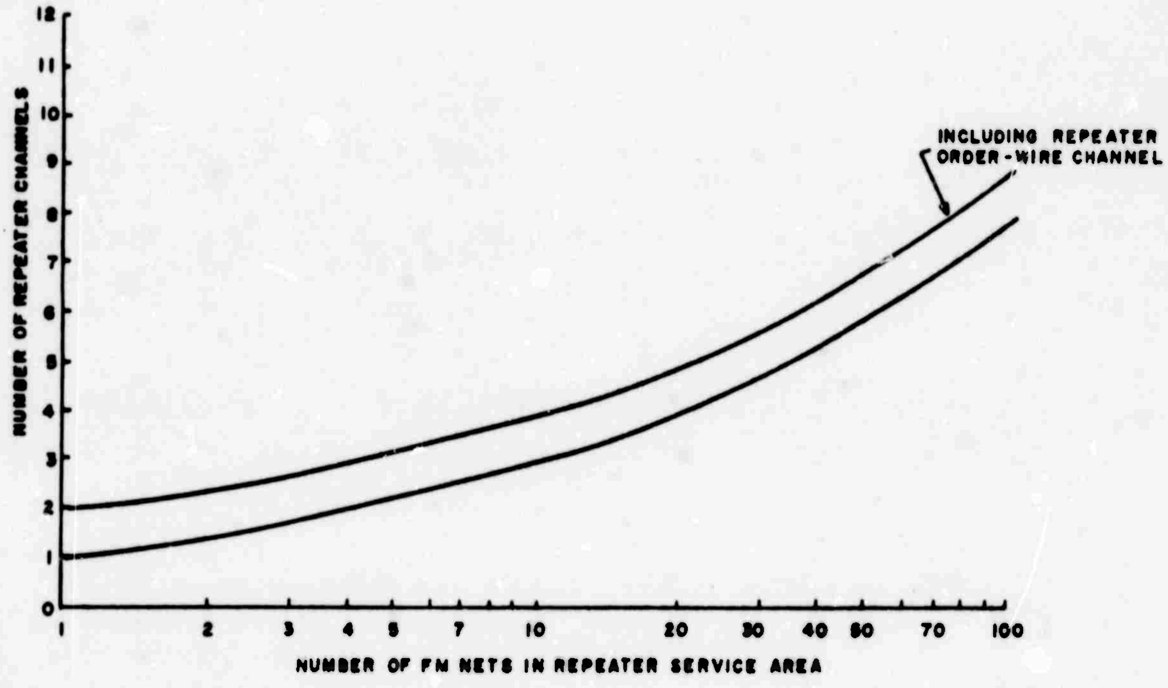


Figure 3-1. Number of Repeater Channels for 95% Probability of Instant Availability

A number of factors enter into the determination of the intelligibility for a relay-equipped link, some of which are only partially predictable.

1. Background noise at speaker's and listener's locations.
2. Effect of band-limiting, clipping, and handset response in transceivers.
3. Internal and external electrical noise at relay and ground receiver.
4. Interference or jamming at platform and at ground receiver.
5. Relay intermodulation in amplifiers common to multiple-access channels.
6. Effects of relay switching in $F_1 - F_1$ mode, including interaction with squelch.
7. Fading due to motion of platform through spatial signal irregularities due to jungle inhomogeneity.
8. Fading due to atmospheric effects.
9. Fading due to relay antenna pattern irregularities, including pattern modulation by rotor blade interaction.
10. Rotor blade modulation interaction with receiver squelch and agc.

Clearly, we are not able to predict the net effect of all of these terms, as only a few of them relate to channel disturbances which produce predictable and repeatable effects on intelligibility.

The channel intelligibility is also related to the time allowed for transmitting a message, since the speaker may add redundancy to the message by repeating himself, and verification of the message may be exchanged with the listener. To avoid the necessity of defining a message delay criterion, we have simply used a 10 db signal to noise plus distortion ratio in a 3 kHz bandwidth as a criterion for minimum satisfactory service. It is noted, of course, that the time-varying nature of the signal, noise, and interference as detailed above may produce a degradation of intelligibility comparable to that introduced by thermal noise and distortion.

3.2.2 Relay Configuration

3.2.2.1 General

It is useful to divide the relay equipment into two categories based on the up and down-link frequencies. Frequency translating (F_1-F_2) relaying is a conventional technique used in connecting line of sight or scatter communications links in tandem or for satellite relaying. The frequency separation permits the use of filtering to keep the transmitter power out of the receiver passband, permitting full duplex multichannel operation.

Common frequency (F_1-F_1) techniques have been applied in telephone relaying, passive reflector relaying, or time shared relaying as used in the Courier satellite. F_1-F_1 relay packages using rapid receive-transmit switching have been developed, (ref. 3.2-1) and work is in progress on non-switched F_1-F_1 relay packages.

These configurations of the relay package impose a number of constraints on the application of relay techniques for tactical applications, as will be considered in the following paragraphs.

3.2.2.2 Frequency Translating Relay

3.2.2.2.1 Configuration

Figure 3-2 illustrates the arrangement of an F_1-F_2 relay package, with a diplexing filter to prevent transmitter power from entering the receiver. In some fixed applications, separation of antennas for two path directions would provide adequate R-T isolation, provided that the relay serves a single channel in push-to-talk operation.

3.2.2.2.2 Operational Considerations

In a conventional FM net, any subscriber may initiate a message to any other. All activity on the net is audible to each subscriber. Break-in is possible only by a subscriber whose carrier level is higher at the desired receiver, although the breaking-in subscriber may not be audible to other subscribers, depending on the path losses.

In a conventional PRC-25 relay configuration, subscriber A and subscriber B may operate on frequencies F_1 and F_2 respectively, using conventional PRC-25 transceivers. This assumes that A and B know, a priori, that the relay will be in operation.

There are two configurations of frequency translating relays with different network constraints. The first configuration is compatible with single frequency transceivers, while the second configuration requires separate receive and transmit frequencies at the transceiver. The first

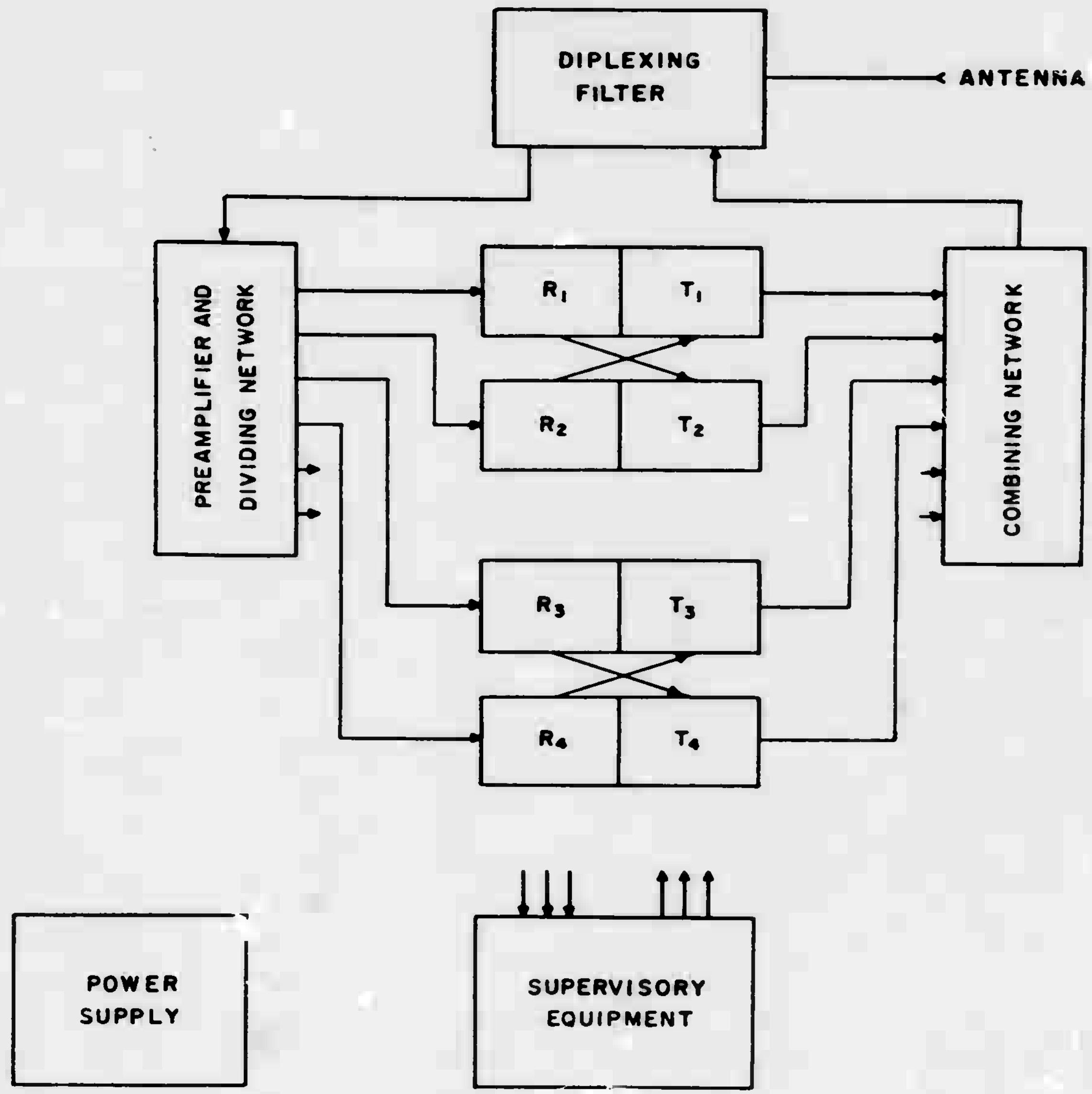


Figure 3-2. Frequency Translating Repeater Configuration (F_1 - F_2)

configuration is shown in Figure 3-3.(a) Note that while A can talk to B and C via the relay, he cannot talk directly to B and C. Subscriber B can talk to C, but does not have the advantage of the relay unless he switches to A's frequency. Traffic can be relayed verbally by A, but at some expense in operating convenience and contrary to standard procedure.

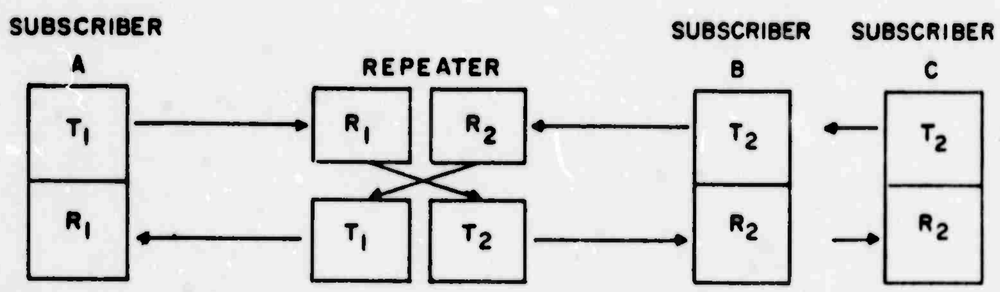
It should also be noted that if B is talking to A, C many not be able to tell that the channel is active, and may interrupt B's message. While A can tell C to stand by until B has finished, this does slow down net operation, and does not protect priority traffic.

A further consequence of the above relay configuration is that if the relay is inoperative, either A, B or C, etc. must switch to a common frequency. It would presumably be designated in the SOI which subscriber would be responsible for changing.

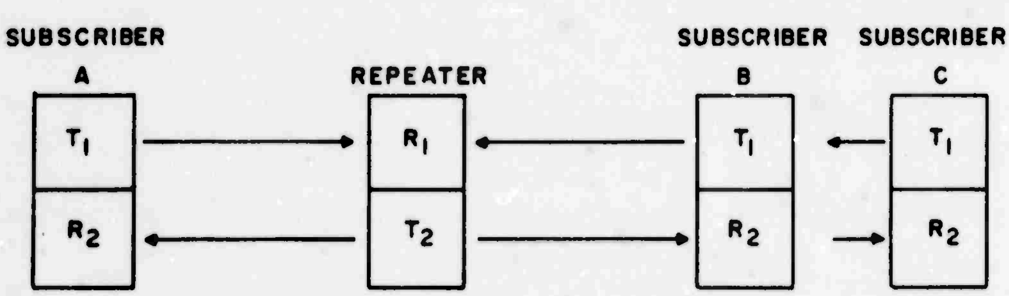
The second frequency translating relay configuration is shown in Figure 3-3. This configuration requires a simpler relay package and is symmetrical with respect to the subscribers. Since all traffic is passed through the relay, each subscriber can listen to all net traffic, and has substantially the same break-in capability as with the conventional FM net. If the relay is inoperative each subscriber must change to a common receive-transmit frequency.

Both of the above configurations assume that the relay is dedicated to a particular net. In order to keep interference from the relay to a minimum, it would be advantageous to use the relay only when necessary. The subscriber who finds himself out of contact with one or more other subscribers in the net must switch from the normal net frequency, F_1, to the relay channel, F_2. The relay translates his signal to F_1 where it is audible to all subscribers in the net. The called party must also switch to F_2 - transmit in order to be heard by the calling party. Other net subscribers may talk among themselves and may hear the other conversation, but can only enter the conversation by switching to F_2 - transmit. Since the receive frequency is fixed, all net subscribers may be informed of the use of the relay. This mode required assignment of an exclusive second frequency for relay operation. Since the relay channel will be used only intermittently, interference will be minimal. An AN/PRR-9 receiver added to the PRC-25 would provide the needed second channel.

If the relay is supervised by an operator (either at the platform or connected by a subsidiary data link) the operator may route traffic to a small number of relayed channels, which may be used more efficiently, although the increased activity on the relay channels will increase the interference generated on these channels. In order to obtain relay service, a



(a) SINGLE-FREQUENCY TRANSCEIVERS
(Subscribe Indicates Operating Frequency)



(b) TWO-FREQUENCY TRANSCEIVERS

Figure 3-3. F_1 - F_2 Network Configurations subscriber calls the relay operator on a SOI-designated order-wire channel, and identifies his net. The operator then directs him to a relay channel (which may or may not be prearranged channel for the particular net) with a new up-link frequency and the previous down-link frequency. The calling subscriber is heard by all other net subscribers. The called party then is requested to switch to F_2 - transmit for the temporary relay connection. All transmissions on F_2 are audible to all subscribers, but the subscribers not requiring the relay may remain in the F_1 FM net mode. Again, use of the PRR-9 as an auxiliary receiver will provide the two-frequency capability required.

Since various FM net subscribers desiring use of the relay call on a common order wire channel, and may not be able to hear one another, they may interrupt each other's requests for relay service. This is the same problem which faces taxi dispatchers, whose receivers are often captured by nearby taxi signals in the middle of a transmission by another taxi. Their response is to tell the interfering taxi to wait until the dispatcher calls him back, which should be equally acceptable in the relay request procedure.

There remains a problem of how to get the relay channel back into the pool when it is no longer required. A particular subscriber might need the relay for only a few seconds, or he might need the relay for twenty minutes or more for directing artillery fire. Perhaps the best answer is for the use of the relay for more than, say, one minute on an exclusive channel basis to require authorization from an appropriate level of command. That is, the operator would accept individual calls from anyone for a 1-minute maximum, and would provide "hot line' service on proper authorization.

3.2.2.2.3 Relay Electronics

Several problems relating to the relay electronics result from F_1-F_2 operation. Separate transceivers (or special purpose single-channel relay equipments) should be used for each channel, as there is no synchronism between the push-to-talk activation on the various channels. Therefore, the receivers must be protected against blocking, overload, or spurious response. This is accomplished partially by choice of operating frequencies and the use of diplexing filters, as described in 3.2.2.2.1 above. Since the receiver squelch may be used to activate the corresponding transmitter channel, it is important that the squelch not be operated by other transmitters in the relay assembly.

Where amplifiers common to several channels are used, as in receiver preamplifiers or transmitter power amplifiers, the distortion generated by amplifier overload must be considered in relation to the weaker signal levels.

Multichannel relay equipment would utilize similar diplexing filter and wide dynamic range receiver techniques to separate the receiver and transmit paths. If conventional FDM-FM modulation is employed, the relay transmitter needs no special linearization to handle multiple channels, and can be operated in a saturated mode.

3.2.2.3 Common Frequency Relay

3.2.2.3.1 Channel Requirements

The attractiveness of common frequency F_1 - F_1, relay operation is largely based on the apparent requirement for a single RF channel and a single transceiver for each net using a relay. However, the operational use of a relay may require more than one channel, and out-of-band interference generation and vulnerability may also require more than one channel per net.

Much of the weight saved with the single transceiver may be required for the commutation timer, the memory, and other switching circuitry for a commutated relay, or for the phase control circuitry presumably needed in a non-switching F_1-F_1 relay.

Duplex operation of a passive reflector F_1-F_1 relay requires two rf channels. Path loss considerations limit the use of passive reflector devices to multichannel point-to-point relaying.

3.2.2.3.2 Relay Configurations

The relay configuration of Figure 3-4 is basic to the commutated F_1-F_1 relay, consisting of a receiver, a memory device, and a transmitter. The memory device, which may consist of a magnetic tape memory for a Courier-type relay, or a holding capacitor in a rapid sampling relay, is loaded while the antenna is connected to the receiver, and unloaded with the antenna connected to the transmitter.

Since the commutation rate is independent of the applied modulation, a multiple channel relay equipment may turn on all receivers or all transmitters in synchronism, avoiding the receive-transmit isolation problems of the F_1-F_2 relay.

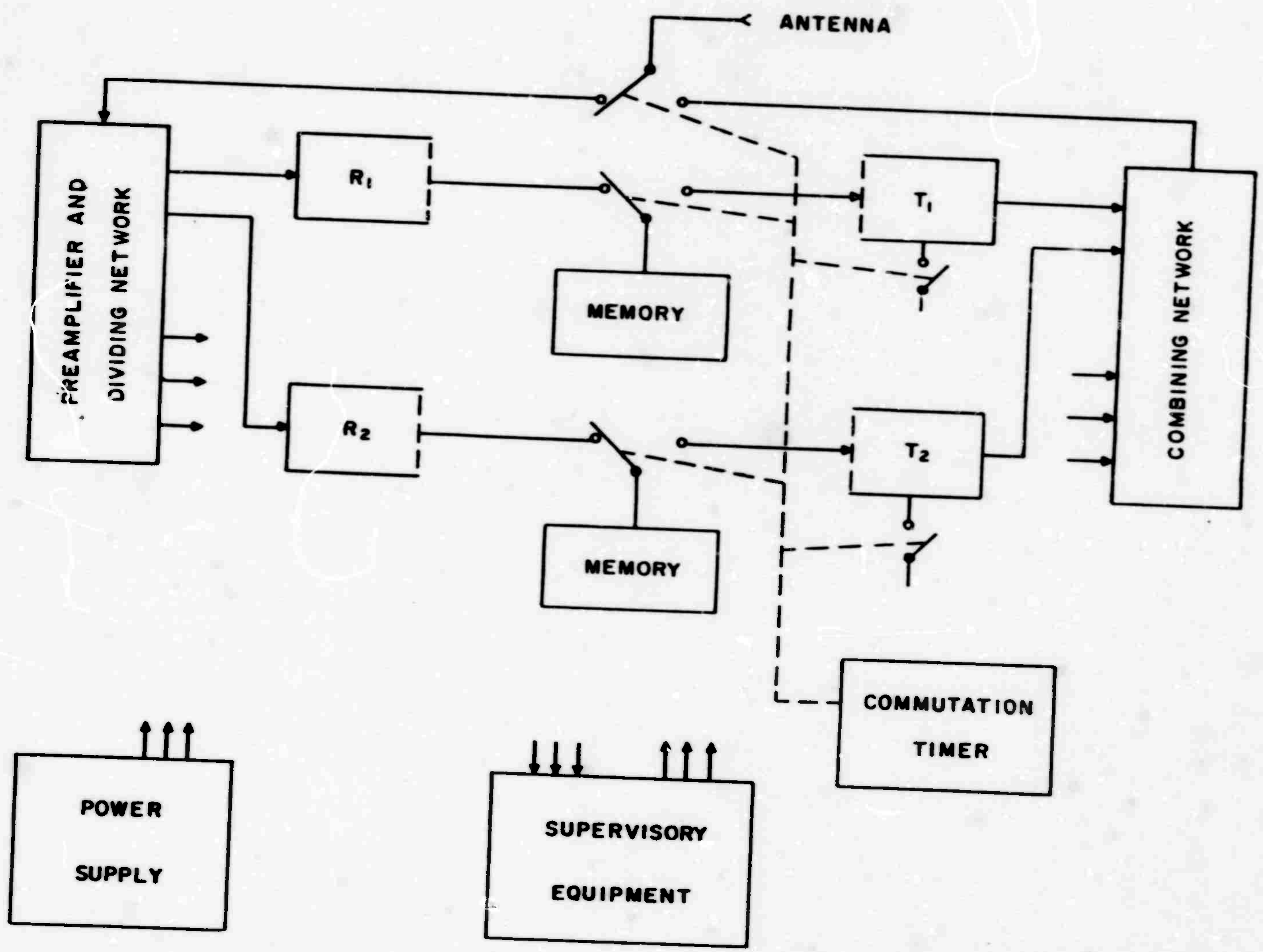


Figure 3-4. Common Frequency Switching Relay (F_1 - F_1)

The non-switching F_1-F_1 relay (a VHF FM version of which is currently under development under an ECOM contract) presumably employs antenna polarization or mode isolation together with coherent generation of a time-quadrature carrier in a manner similar to a CW radar in order to obtain R-T isolation. A development effort for a similar relay for UHF AM operation has been initiated by the Air Force Systems Engineering Group at Wright-Patterson AFB. Development of a non-switching F_1-F_1 relay for more than one RF channel appears to be a formidable task.

A passive reflector link involves the same basic terminal configuration as would be associated with a line of sight link, with the reflector providing an improved path-loss situation.

3.2.2.3.3 Operational Considerations

There are several features of the F_1-F_1 relay which lead to problems in relay applications. If the relay operates on the original FM net frequency (as assumed in claiming single frequency operation) some subscribers will receive signals both from the relay and directly from another subscriber, leading to potential system degradation for some subscribers as the price for improving performance for other subscribers. If the switching rate of the F_1-F_1 equipment is well above the audio range, the relay could readily generate interference, possibly over several adjacent channels.

These problems may be alleviated somewhat by using the relay on an as-required basis. One means would be to use a second channel for relay operation, negating the channel requirement advantage. Each subscriber would require an auxiliary receiver tuned to the relay frequency.

If the relay is supervised by an operator, a subscriber needing augmentation of his range may call the operator on an order wire channel to request service, then return to his original net frequency, where the operator will provide temporary relay service. There is still the possibility that subscribers in the net who did not need the extended range may find their circuit degraded by multipath.

Use of a switching F_1-F_1 relay may pose problems of compatibility with digital modulation modes, the use of which will become increasingly important in the next few years.

3.2.2.3.4 Switching Rate Considerations

The switching rate of a commutated F_1-F_1 relay as shown in Figure 3-4 is important in determining the performance of the relay itself as well as the interference generation and vulnerability interfaces with other systems.

The following factors have been considered in attempting to estimate F_1-F_1 relay performance potential:

a) Receiver IF pulse response
b) Receiver squelch rate
c) Intelligibility of chopped speech
d) Relay output spectrum
e) Ground echo return
f) Precipitation echo return

In response to a series of carrier pulses, the receiver IF will provide a response similar to a low-pass filter of half the IF bandwidth. For the 36 kHz PRC-25 bandwidth, the response shape is therefore similar to an 18 kHz low-pass filter. Figure 3-5 (ref. 3.2-2) shows the response corresponding to a fixed repetition rate and various values of equivalent low-pass bandwidth. If the repetition rate is less than 0.25 of the IF bandwidth, the carrier will decay to zero during the pulse interval. As the receiver will be provided with enough gain to limit on background noise, the output noise level may rise to a level comparable to the signal level in the inter-pulse interval. The receiver squelch time constant is typically a few hundred milliseconds, so the squelch will not be able to suppress the noise burst, and a severe degradation of the signal to noise ratio will result. For lower carrier to noise ratios, the degradation will extend to higher switching rates than for high carrier to noise ratios, since the carrier may more easily drop below threshold.

Miller and Licklider (ref. 3.2-3) have investigated the effects of switching speech on and off at various rates, and the effects of alternating speech and noise. Figures 3-6 and 3-7 show some of the results of this investigation. It is particularly noteworthy that articulation reaches a peak at switching rates of the order of 20-50 Hz, and reaches a minimum at frequencies of several hundred Hz. For switching speeds of the order of 10-15 Hz, the presence of noise in the gaps makes speech more acceptable although it does not improve the intelligibility.

For rapid switching rates, an appreciable fraction of the signal spectrum falls outside the IF passband, resulting in an increasing loss of carrier to noise ratio up to the point where the first switching sidebands are located beyond the IF passband. The power lost in this manner is of the order of 10 db for cosine-squared keying waveforms with 33% transmit duty cycle, as used in Motorola's experimental F_1-F_1 relay (ref. 3.2-1).

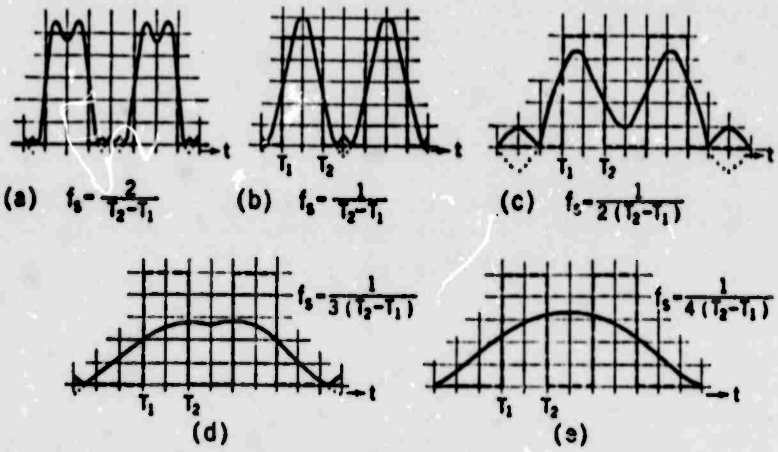


Figure 3-5. Effect of Bandwidth on the Transmission of Detail (After Goldman)

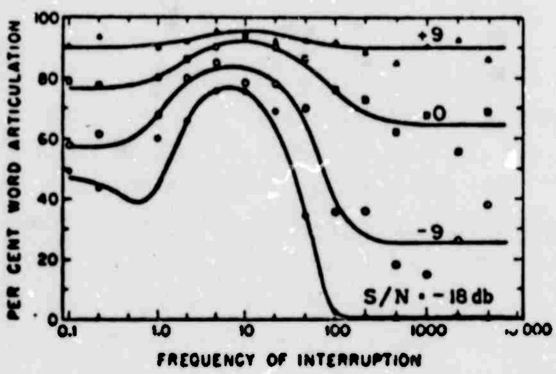


Figure 3-6. Effect of Masking of Continuous Speech by Interrupted Noise, 50% Duty Cycle (After Miller and Licklider)

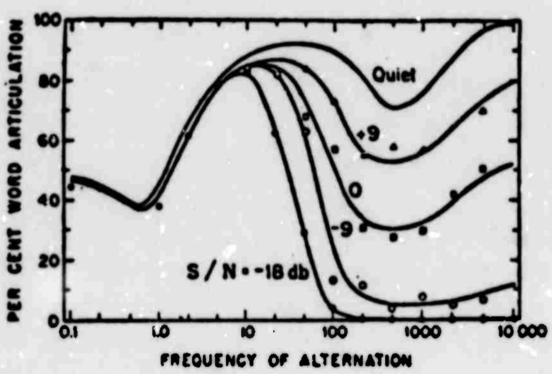


Figure 3-7. Effect of Alternation of Speech and Noise Intervals, 50% Duty Cycle (After Miller and Licklider)

This power loss may be overcome by increased transmitter power on the down-link, although there is a loss due to the reduced relay receiving period on the up-link which cannot be compensated. Since the components of the switching spectrum are each modulated by the original audio waveform, there will be a range of switching speeds where the FM spectra around the carrier and around the first switching sideband are both within the IF-discriminator passband, producing distortion. This suggests that switching rates of the order of half the IF bandwidth plus the peak deviation are needed to minimize distortion.

Echos of the relay output signal from the ground may degrade the relay receiving signal-to-noise ratio, and may confuse the squelch activation of the transmitter.

The various factors described above have been combined to give a postulated relationship of switching rate and articulation, in Figure 3-8. Apart from the low-frequency asymptote at 50% articulation, the values are all uncertain, and are intended only to indicate trends. The relative magnitude of the low and high frequency articulation peaks is likewise uncertain. A comprehensive experimental program would be expected to be more productive than theoretical investigation,* in view of the interaction of electrical and psychoacoustical phenomena.

As previously noted, once switching speeds are below the Nyquist rate, the relay will not be compatible with nonsynchronous digital modulation formats.

3.2.2.4 Summary

Several considerations have been discussed above bearing on the selection of F_1-F_1 or F_1-F_2 relay modes in terms of operational restrictions, relay-transceiver interfaces, and relay realization. Preliminary conclusions are that:

1) For the initial time frame, F_1-F_2 relaying is most likely to provide useful service.

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* A brief qualitative investigation of speech performance with various switching rates conducted by Page Communications Engineers, Inc. verified the low frequency maximum, but failed to show a high frequency peak. The need for more detailed measurements is evident.

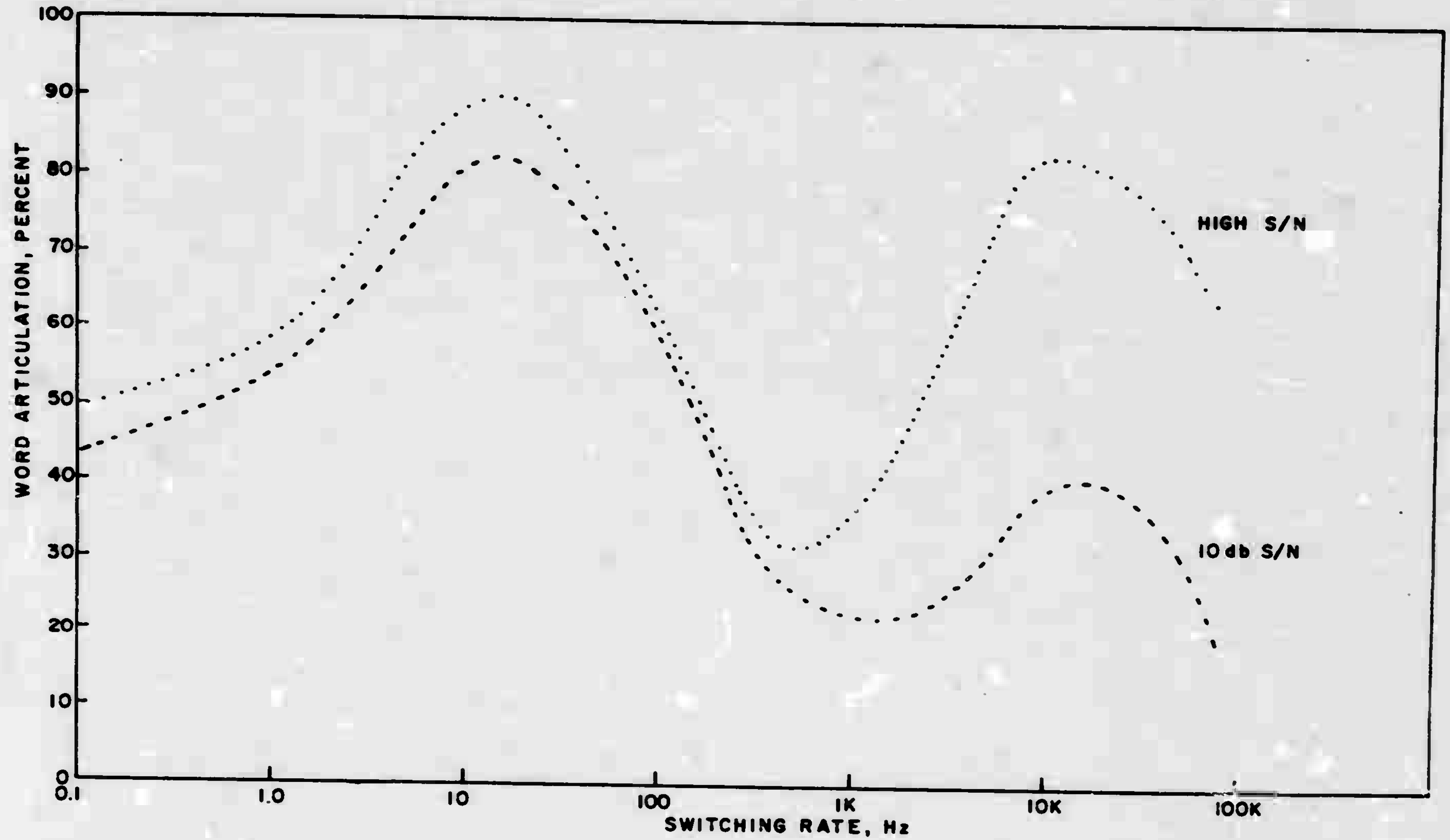

Figure 3-8. Postulated Relative Articulation for F_1 - F_1 Switching Relay

2) Compatibility of a single transceiver F_1-F_2 relay with AN/PRC-25 type equipment requires issuing AN/PRC-9 or similar receivers for second-frequency operation.

3) Frequency allocation problems and varying military estimates of the demand for relay service suggest that supervised relays with limited numbers of channels may best serve the initial and interim requirements.

4) F_1-F_1 switching relay equipment utilizing low speed switching appears to be compatible with VHF-FM tactical radio equipment, and may be implemented simply enough to be considered for the interim time frame, but is not compatible in general with digital modulation modes.

5) Non-switching F_1-F_1 relay development may lead to improved channel quality, but does not appear to be suitable for simultaneous relaying of 2 or more channels.

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3.3 PROPAGATION

3.3.1 Design Criteria

3.3.1.1 Line of Sight Systems. Line-of-sight system design must provide adequate protection against the three most serious sources of propagation degradation. These are:

1. Earth bulge fading
2. Destructive interference fading (multipath)
3. Space wave fadeout associated with ducting

In addition, protection must be provided against precipitation absorption outage for paths sufficiently high in frequency for this to become a factor. For VHF and UHF relay operation, the precipitation effects can be ignored. The relay antenna height is also sufficient to minimize problems due to space wave fadeout. In cases where a terminal is immersed in a jungle media, the propagating ray, once free of the jungle canopy, lends itself to the line-of-sight analysis described here.

3.3.1.1.1 System Margin

The available system margin A (defined as the maximum permissible attenuation below free space for a specified grade of service) is given in db by Norton, et. al. (ref. 3.3-1) as

$$\hat{A} = P_t + G_p - P_{mr} - L_{bf} - L_{tt} - L_{tc}$$

where P_t is the transmitter power in decibels above 1 watt

G_p is the path antenna gain, equal to the sum of the maximum gains G_t and G_r of the transmitting and receiving antennas, less any polarization and beam orientation loss

P_{mr} is the operating sensitivity of the receiver in decibels above 1 watt

L_{bf} is the free-space path loss

L_{tt} is a loss factor which allows for transmission line loss and mismatch terms

L_{tc} is a loss factor which allows for antenna circuit losses.

For a path length d (in km) and a radio frequency f (in MHz), L_{bf} is given by:

$$L_{bf} = 32.45 + 20 \log_{10} f + 20 \log_{10} d$$

The data presented herein are developed on a probabilistic basis with some allowances for the range of atmospheric conditions which may be encountered. In this section it is assumed that the ground terminal is in a cleared area free of the jungle canopy. For any particular point-to-point path, sufficient meteorological data and path terrain profiles could be developed to permit a detailed analysis by deterministic methods. However, such a procedure appears ineffectual for the air-to-ground relay since movements of the platform by a few centimeters can significantly alter the calculated results.

3.3.1.1.2 Propagation Geometry

The path loss between the ground based transmitter (or top of jungle canopy) and relay is calculated with the geometric representation shown in Figure 3-9. The slant range, r_o, is determined from the ground distance, d, and the relay height, h_r. As the relay continues to increase in distance from the ground transmitter, the angle θ (measured from the zenith) increases. The horizon is reached and line-of-sight transmission ceases as θ approaches $\approx$ 90 degrees. Figure 3-10 illustrates the slant range for several platform altitudes.

The refractive nature of the troposphere and the variations of refractive index with altitude alter the path of the line-of-sight transmission. The gradient of refractivity (dN/dh) determines the amount of ray bending. When the gradient (dN/dh) is positive, rays will be bent upwards; when the gradient is negative, they will be bent downwards. It is customary to allow for this bending by employing the concept of an effective earth's radius wherein the curvature of the rays is subtracted from that of the earth to determine an artificial earth of radius $a = ka_o$ (where a_o = 6370 km). Using this method, the propagation path may be represented with straight lines and the effective earth ratio, k, is given by:

$$k = \left(1 + \frac{a_o}{n} \frac{dn}{dh}\right)^{-1}$$

The local refractive index, n, is determined (ref. 3.3-2) from the published values of refractivity, N, by:

$$n = 1 + (N)\ 10^{-6}$$

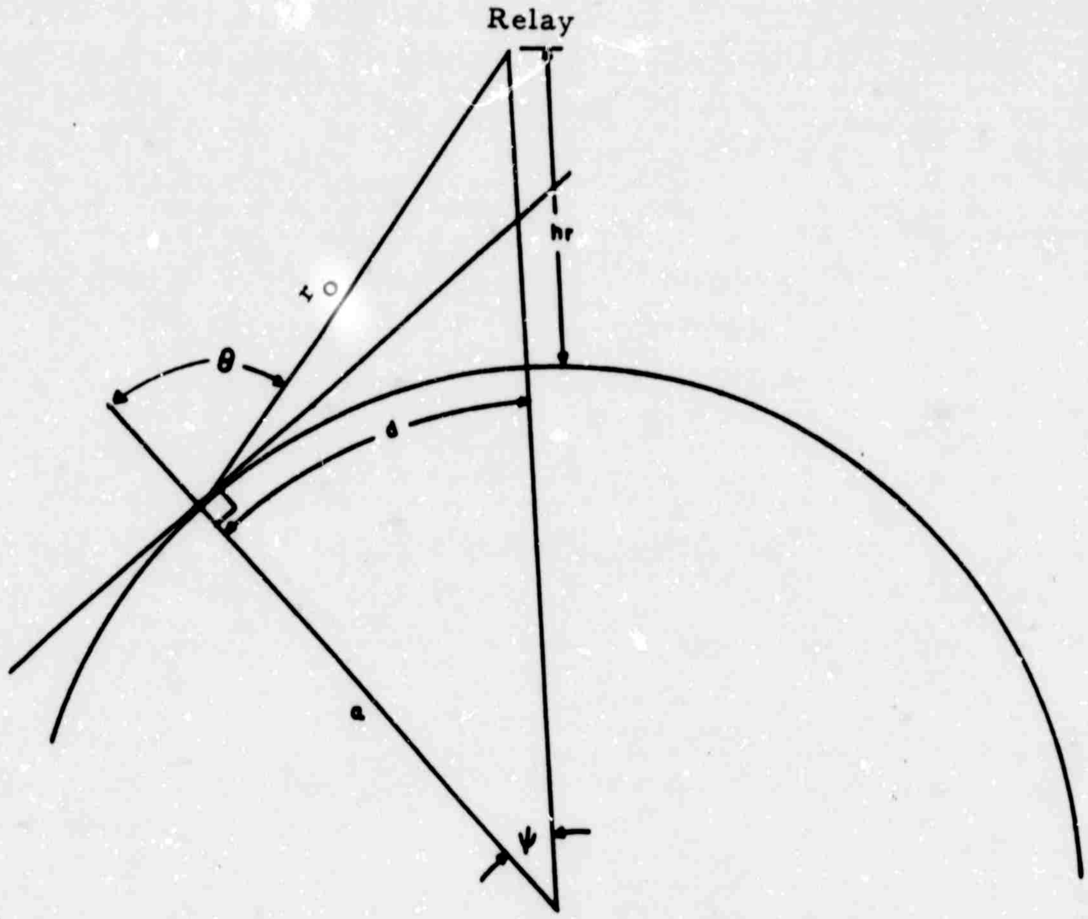


Figure 3-9. Relay Geometry

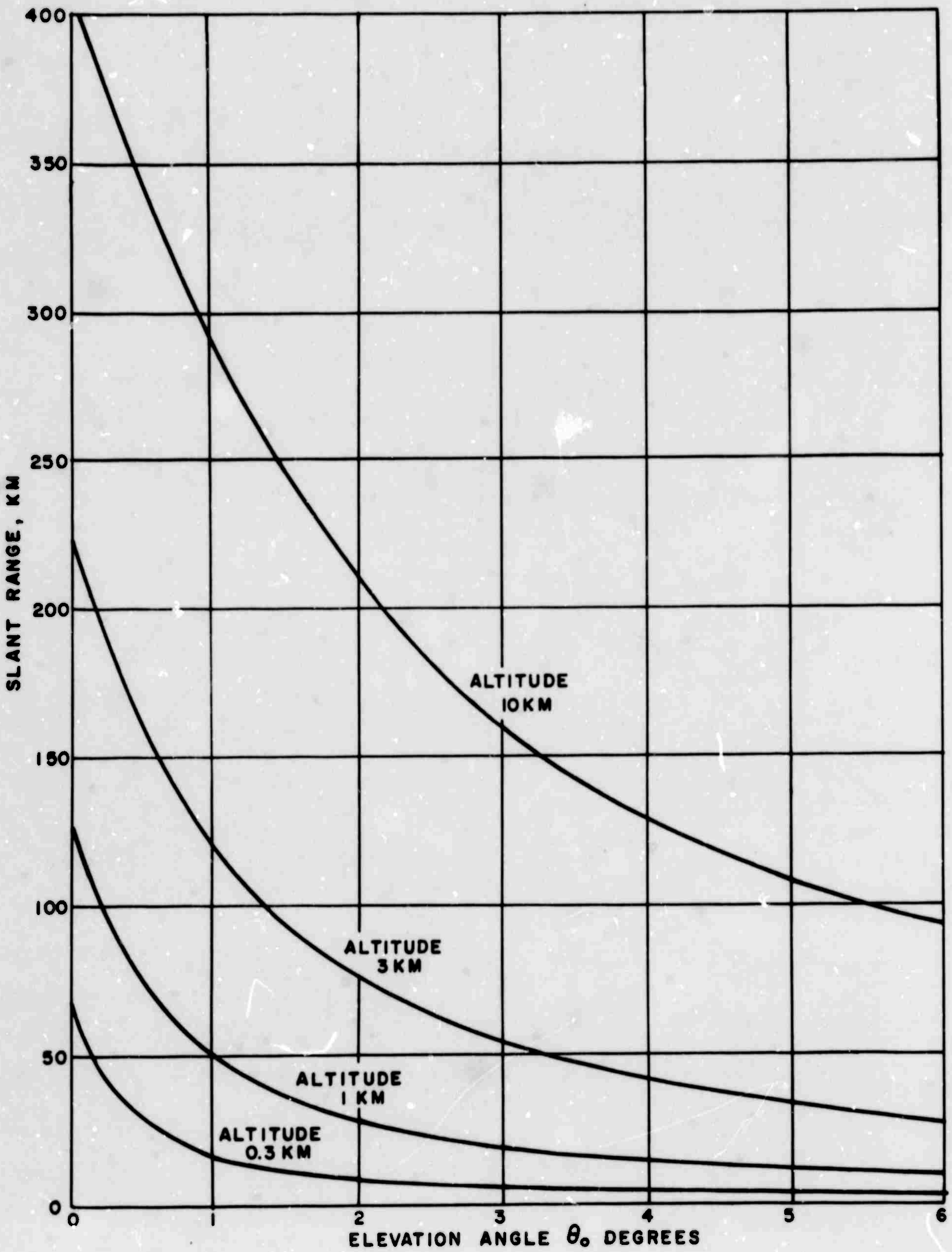


Figure 3-10 Slant Range as a Function of Platform Altitude

The gradient (dn/dh) is similarly obtained from values of dN/dh by:

$$dn/dh = (dN/dh)\ 10^{-6}$$

3.3.1.1.3 Earth Bulge Fading

During certain percentages of time, the refractivity gradient of the troposphere increases to values which yield a small effective earth's radius. As the radius decreases, the bulge of the earth may obstruct the line-of-sight path. During this percentage of time, the path loss increases rapidly as the propagation mode changes to diffraction or troposcatter. A quantitative discussion of the probable earth bulge fading effects is covered in Section 3.3.3, Propagation Variabilities.

3.3.1.1.4 Destructive Interference Fading

Since it has been determined that very little antenna gain can be used effectively, it is necessary to make appropriate allowances for multipath interference. In contrast with earth-bulge fading, phase interference fading arises from large negative values of dN/dh, permitting a phase difference of $n\pi$ radians between the direct and reflected ray. Interference fading may generally be negated by means of space or frequency diversity. This type of fading may be expected to be most severe on paths with smooth terrain. Therefore, consideration of multipath with a smooth earth model protects the systems against the worst-case situation.

If the phase difference between the direct and reflected rays is designated $2\pi\, \nu(f)$, and a phase change of π radians on reflection is assumed, the attenuation (with respect to free space) due to addition of the two waves at the receiver is given by:

$$A(f,k) = 20 \log_{10} \left| 2 \sin [\pi\, \nu(f,k)] \right|$$

for a specified effective earth's radius constant, k. This simplified model is conservative, in that any focusing or defocusing of the reflected ray tends to decrease the maximum possible value of A (f,k). It may be demonstrated that for a grazing ray, $\nu(f, k_g) = 0$; and, $\nu(f,k)$ increases monotonically with increasing k, i.e., with decreasing dN/dh.

In the high altitude relay instance, the statistics of short-term phase-interference fading can be represented by a Rayleigh distribution. This model has been widely used for system design where a multiplicity of parameters (such as platform height and movement, terrain features, etc.) are uncertain. Figure 3-11 indicates that a fade margin of 38 db should provide

* R.L. Marks, et al., "Some Aspects of FM design for Line of Sight and Troposcatter Systems", AD 617 686, April, 1965, p. 53.

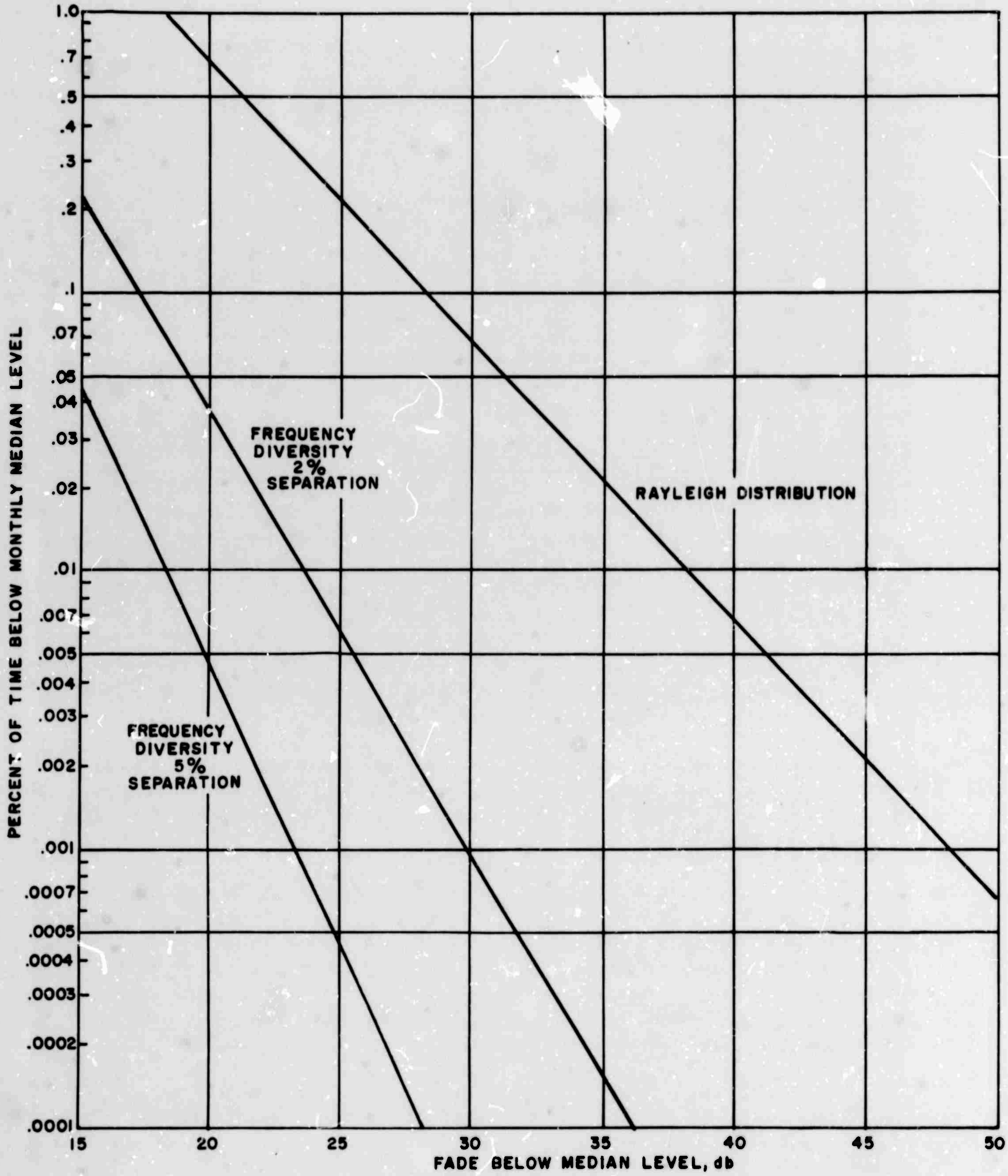


Figure 3-11 - Statistical Distribution of Interference Fading a 99.99% short-term reliability. Frequency diversity, with a frequency separation of approximately 5% yields the same percentage of interference protection with a fade margin of only 18 db.

3.3.1.2 Propagation Through a Jungle Canopy

3.3.1.2.1 Analysis

The phenomenon of radio propagation loss introduced by jungle foliage has been observed for many years and has received particular attention under the pressure of military operations in Southeast Asia. In an effort to improve tactical radio communications in this and similar areas by the use of high altitude airborne relays, it is necessary to develop models for air-to-ground propagation over terrain characterized by mountains, jungle, foliage, and tropical climate conditions.

In other areas where counterinsurgency operations might be required, quite different propagation conditions may exist. It would appear, however, that the propagation to be expected in deserts, tropical grasslands, or temperate climates would be more accurately predicted by contemporary theory than is tropical jungle propagation. For this reason, and for the immediate time-frame application of relay techniques, the study has concentrated on the jungle communications problem as observed in Viet Nam and Thailand.

Extensive measurement programs have been conducted in Thailand to determine the radio characteristics of jungle foliage and to evolve techniques for the prediction of the range of communications equipments. A selected bibliography of references to jungle propagation and related topics is presented in Section 3.6.

The approach taken to the prediction of path loss for a ground transceiver to airborne relay is to divide the loss into two components. The first component is a systematic loss computed on the basis of an idealized slab model of the jungle foliage. The second component is a statistically described loss representing the inhomogeneity of the real jungle, the effect of the foliage on the transceiver antenna pattern, and the angular fluctuation of the antenna gain at the relay platform. It may be possible and useful to separate the latter term. Experimentally determined electrical parameters of the jungle are used in computing the systematic component. Measured distributions of the difference between actual loss and systematic loss serve to provide estimates of loss variability.

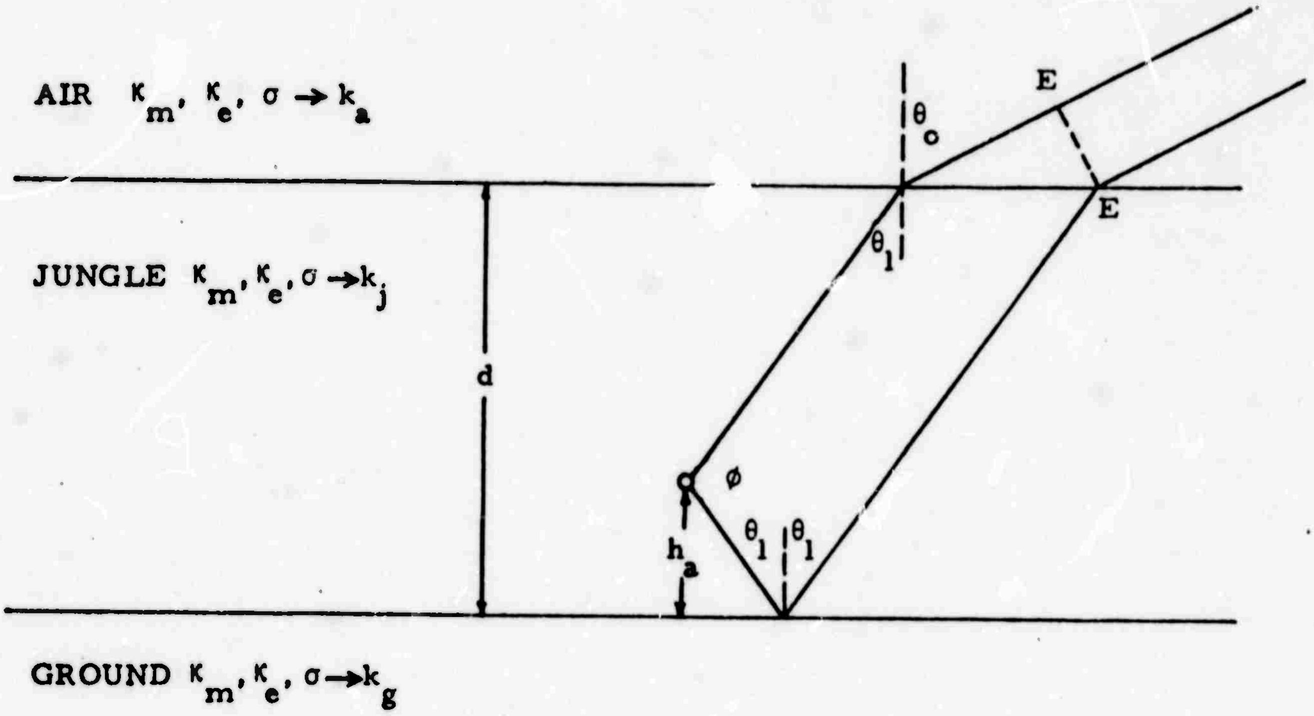
The following paragraphs describe the propagation analysis and computational procedure, the results of the computations, and the implications for the design of relay systems.

3.3.1.2.2 Propagation Model

For a number of years a growth of vegetation has been regarded as a lossy dielectric for purposes of radio wave propagation. Gerber and Werthmueller (ref. 3.3-2) measured quite directly the intensity of electric polarization of the trees of a forest as a function of temperature and type of tree. From these measurements, they then predicted and subsequently verified by measurement the path loss for medium frequencies for propagation through forest. Quite recently Sachs and Wyatt (refs. 3.3-4 and 3.3-5), assuming antennas located in a slab of lossy dielectric between earth and air, have performed an incisively analytical integration of the traditional Bessel transforms (ref. 3.3-6) generally descriptive of propagation in and near lossy media. In reference 3.3-5 Sachs correlates the measurements of Jansky and Bailey (ref. 3.3-7) with predictions based on his analytical representation and finds a very substantial agreement (compare pages 46 and 55 of ref. 3.3-5) -- to within 1.5 db for the 6 - 100 MHz range and to within 4 db for the 250 - 400 MHz range. Lateral wave propagation has been studied by Tamir (ref. 3.3-8) for jungle to jungle communications with results in general agreement with those above.

Although the Bessel transform is an elegant and properly general representation of propagation, it is recognized that it corresponds in the general case to a superposition of plane waves (compare ref. 3.3-6, page 577) and in suitable circumstances may be replaced by a plane wave or ray representation. In the instance of propagation between a jungle-based antenna and an aircraft-based antenna, it is sufficient to consider a direct and a ground-reflected ray because any additional rays are too attenuated to contribute significantly to the net result.

A computer sub-routine of a larger propagational program has been established to compute the pattern of interference between the direct and ground-reflected rays in the air space above a jungle-sited antenna. More specifically, referring to Figure 3-12 inputs to the computer are permeability, permittivity and conductivity for earth and for jungle and--as the program stands--values of permeability and permittivity different from unity may be specified for the air-space, should one wish to do so. Additionally, depth of jungle and height of antenna as well as frequency and polarization are inputs. A quarter-wave dipole is assumed in the expectation that the phased gain of an actual source would be similar to this.



$$\kappa_m = \frac{\mu}{\mu_o} = \frac{\text{permeability of medium}}{\text{permeability of free space}}$$

$$\kappa_e = \frac{\epsilon}{\epsilon_o} = \frac{\text{permittivity of medium}}{\text{permittivity of free space}}$$

σ = conductivity of medium

k = propagation constant = $\epsilon \mu \omega^2 - j \omega \mu \sigma$

Figure 3-12. Geometry of Slab Model

The output of the subroutine is the amplitude of the interfering pair of rays versus whatever schedule has been specified for the independent variable, θ_o.

3.3.1.2.3 Propagation Analysis

For a conducting medium, Snell's law requires that θ_1 of Figure 3-12 be complex. This corresponds to a real angle of propagation determined by

$$\cos \psi = \frac{\mathrm{Re}\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o}}{\sqrt{\left(\mathrm{Re}\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o}\right)^2 + k_a^2 \sin^2 \theta_o}}$$

where ψ = angle of propagation

k_a = complex propagation constant in air

k_j = complex propagation constant in jungle

θ_o = zenith angle of relay platform

This angle is used together with the antenna height h_a and the jungle height d to compute the direct and indirect ray lengths within the jungle and the distance between rays at the air-jungle surface. The ray lengths are used with θ_1 (Figure 3-12) to compute attenuation and phase lengths of the two rays within the jungle. The phase length of the direct ray is augmented by the projection of the distance between rays at the jungle-air surface. The reflection coefficient at the jungle-ground surface is computed as in Stratton (ref. 3.3-6, pp. 493, 494).

The properly phased and attenuated rays are combined at the plane E-E of Figure 3-12. The absolute value is multiplied by transmission coefficients, following generally Stratton's development (ref. 3.3-6, pp. 495, 496). For vertical polarization the square of the transmission coefficient is

$$T_v^2 = \frac{4\,\left|k_a/k_j\right| \cos\theta_o}{\left|1 + \dfrac{\mu_a k_j}{\mu_j k_a} \dfrac{\cos\theta_o}{\sqrt{k_j^2 - k_a^2 \sin^2\theta_o}}\right|^2} \times \frac{\sqrt{\left(\mathrm{Re}\sqrt{k_j^2 - k_a^2 \sin^2\theta_o}\right)^2 + k_a^2 \sin^2\theta_o}}{\mathrm{Re}\sqrt{k_j^2 - k_a^2 \sin^2\theta_o}}$$

where T_v = transmission coefficient for vertical polarization

μ_a = permeability of air

μ_j = permeability of jungle

and for horizontal polarization is

$$T_h^2 = \frac{4 \left| k_a/k_j \right| \cos \theta_o}{\left| 1 + \frac{\mu_j k_a}{\mu_a} \frac{\cos \theta_o}{\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o}} \right|^2} \times \frac{\sqrt{\left(Re\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o} \right)^2 + k_a^2 \sin^2 \theta_o}}{Re\sqrt{k_j^2 - k_a^2 \sin^2 \theta_o}}$$

These coefficients account for the increasing divergence of rays emerging from the jungle at θ_o for real incident angles ψ_c at which total reflection occurs (T=0). For small conductivity the critical angle to good approximation is

$$\psi_c = \arc \sin \sqrt{\frac{1}{\kappa_j}}$$

where κ_j is the dielectric constant of the jungle.

This procedure has been converted into a Fortran - IV Program with the following input/output requirements.

The input data required by the main program are:

a. Slab model constants
b. Antenna data (relay)
c. Antenna data (jungle)
d. Canopy height
e. Frequency
f. Reference atmosphere, N_s
g. Height of relay
h. Earth distance from relay to jungle antenna

From this, the program computes and prints the following outputs:

a. Total path loss, including jungle propagation, free space, ground reflection within the jungle and atmospheric absorption.

b. The elevation angle outside the canopy computed from the distances, reference atmosphere and heights given.

c. The elevation angle inside the canopy computed from boundary conditions determined by the slab constants.

3.3.2 Propagation Predictions

3.3.2.1 Introduction

From the results of the computer program described in the previous section, parametric curves of the systematic component of path loss have been prepared. The computer program, in effect, translates the radiation pattern of a vertical radiator immersed in the jungle into an effective free-space pattern in the half-space above the jungle. It includes the effects of the amplitude and phase of the ground-reflected ray, attenuation and retardation of the direct and reflected rays through the jungle, transmission loss (partial reflection and dispersion) through the jungle-air interface, and coherent combination of the resultant two rays in a plane normal to the direction of free-space propagation. It is assumed that a path through the jungle media incurs higher losses than normal line-of-sight (free-space) propagation. Thus, this section is weighted toward jungle propagation analysis.

3.3.2.2 Loss Dependence on Relay Height

For the transceiver to relay path geometry indicated in Figure 3-9 and Figure 3-10 the systematic portion of the path loss has been computed. Figures 3-13 and 3-14 show path loss in db (consisting of free space loss plus loss in penetrating the jungle, as above) versus lateral distance between the ground transmitter and the sub-relay point. These figures contain six curves parametric in relay height h_r according to the schedule h_r = 0.3, 1.0, 3.0, 10.0, 30.0, 100.0 km. The curves are presented for 30 and 76 MHz and for a canopy height of 20 meters. The antenna within the jungle is assumed to be a quarter-wave whip at 76MHz and correspondingly shorter, electrically, at 30 MHz.

Electrical constants are:

	Air	Jungle	Ground
Conductivity σ (mho/m)	0	.00015	.02
Permittivity ϵ_r	1.0	1.02	15.0

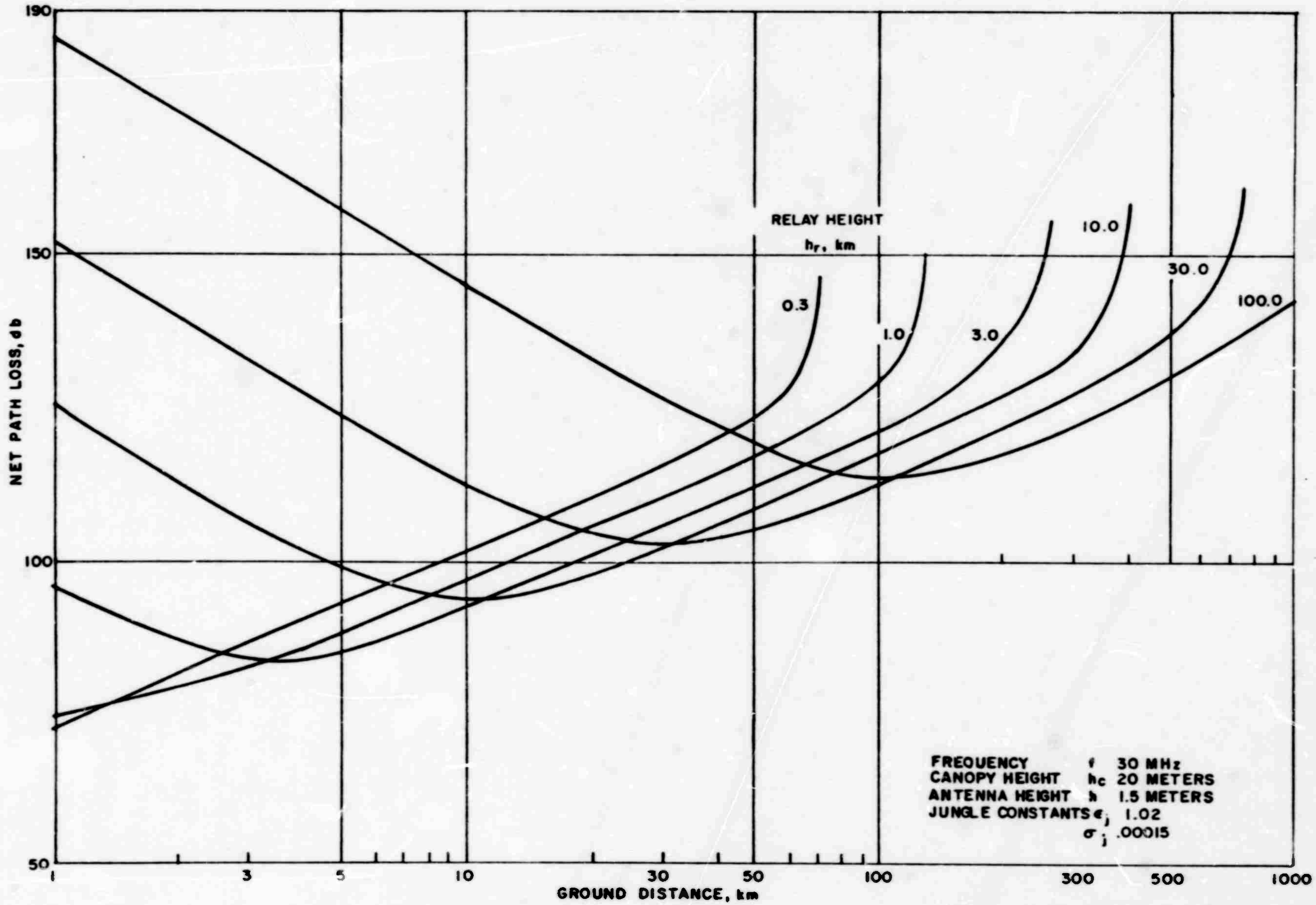


Figure 3-13. Path Loss for Transmission From Radio Set in Jungle to Relay at Height h_r vs Ground Distance (30 MHz) Frequency

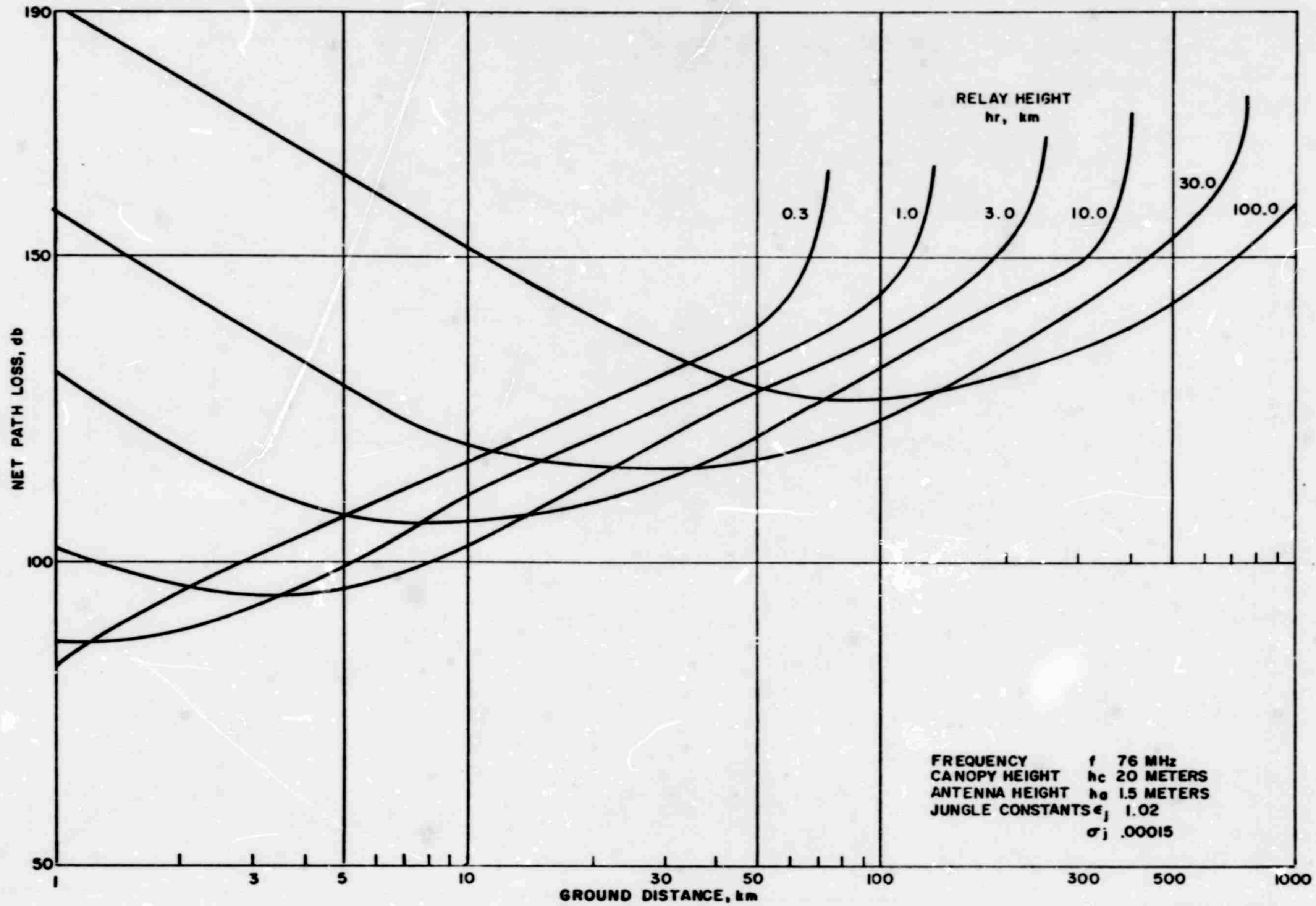


Figure 3-14. Path Loss for Transmission from Radio Set in Jungle to Relay at Height h_r vs. Ground Distance (76 MHz) Frequency

The jungle constants above are based upon Parker and Hagn's measurements of specific permittivity (ref. 3.3-9) and Sach's best fit value of conductivity (refs. 3.3-4 and 3.3-5). Prior measurements by Parker and Hagn have indicated values of permittivity of the order of 1.2.

3.3.2.3 Sensitivity to Jungle Parameters

Since Parker's and Sach's analyses agree for representative values of jungle conductivity no specific analysis of sensitivity to this parameter has been performed. However, Sachs has computed curves between two antennas immersed in the jungle for $\sigma_j = .0001$ and $\sigma_j = .0002$ (refs. 3.3-4 and 3.3-5), and these can be used to obtain some idea of the sensitivity to σ_j.

While Parker's early transmission line measurement indicated a value of $\epsilon_j = 1.2$, Sachs uses a value for permittivity $\epsilon_j = 1.02$ in his analyses. These values have been used here. Figures 3-15 and 3-16 have been plotted to illustrate the sensitivity of path loss to ϵ_j. These curves are for 30 and 76 MHz respectively.

It may be seen that little sensitivity to ϵ_j occurs at high ray angles; however, as the ray angle approaches the horizon varying amounts of path loss reduction with increasing ϵ_j are evident from the curves. Figures 3-17 and 3-18 illustrate the effects of jungle canopy height. These are plotted for 30 and 76 MHz at canopy heights of 10, 20 and 30 meters.

3.3.2.4 Effect of Dipole Antennas

The principal effect of the dipole antenna pattern is some reduction in path loss at longer ground distances, and a rise in loss at extremely short ranges, corresponding to the nulls of the dipole pattern. Portions of the curves corresponding to more than 30 db total null depth at high angles are unlikely to be realized due to the uncertainties of antenna orientation stability and fill-in resulting from jungle-scattered energy at other angles. The small bending or distortion in the curves is due to the interaction of the antenna pattern, the ground reflection and the canopy-air boundary refraction. The pattern differences between electrically short and quarter-wave whips are small due to the normal higher angle of operation and scattering within the jungle.

3.3.2.5 Antenna Gain for UHF Multichannel Relay

When operating at frequencies in the range of 1700 to 2200 GHz, antenna gains in excess of 20 db would normally be used. When examining the path geometry using a relay platform, it is obvious that the vehicle could be at any elevation angle from 0 to 90 degrees and at altitudes ranging to 10 km or more. Since this range is large, it appears infeasible

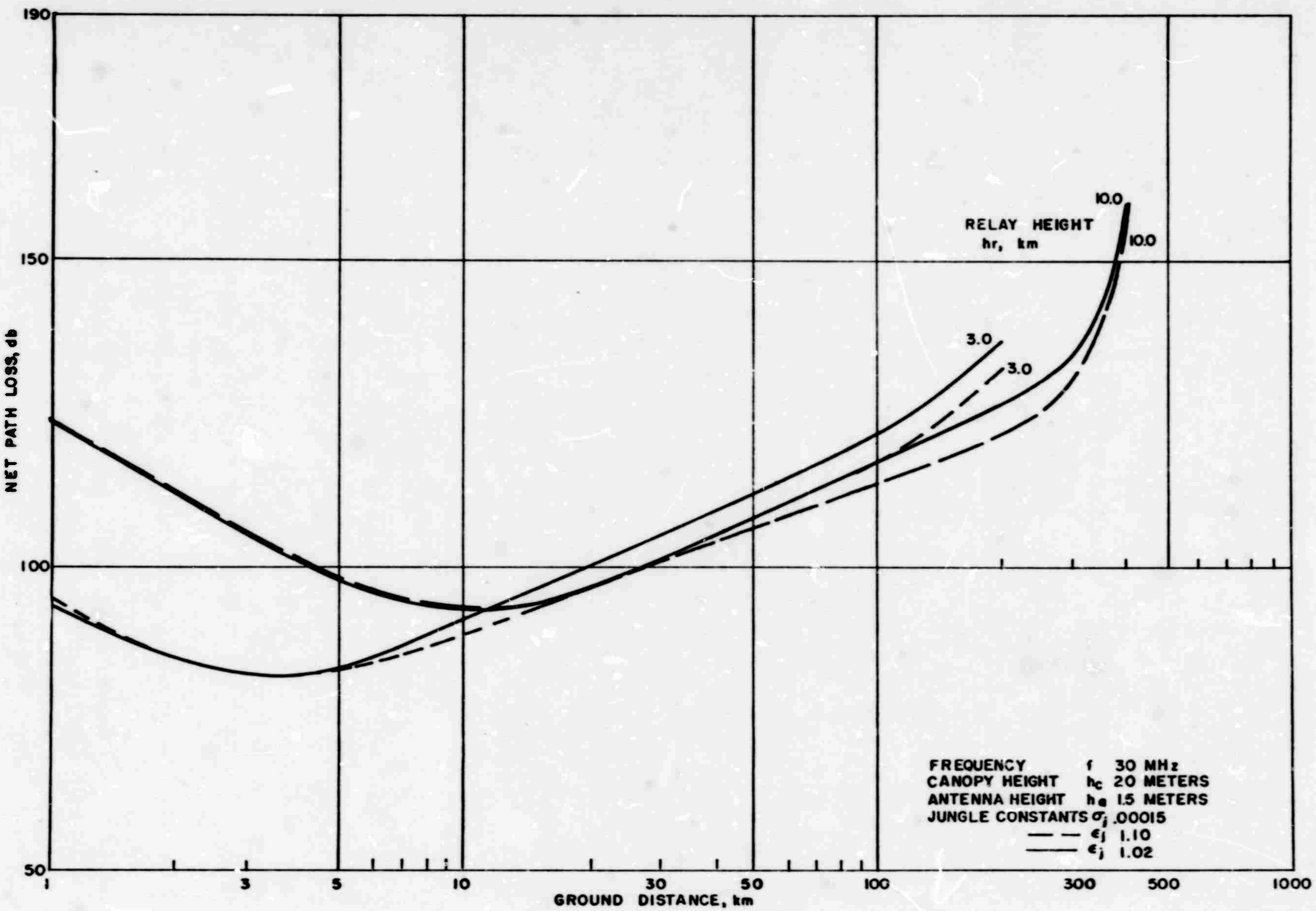


Figure 3-15. Data Loss vs Ground Distance with Variations in Permitivity (30 MHz Frequency)

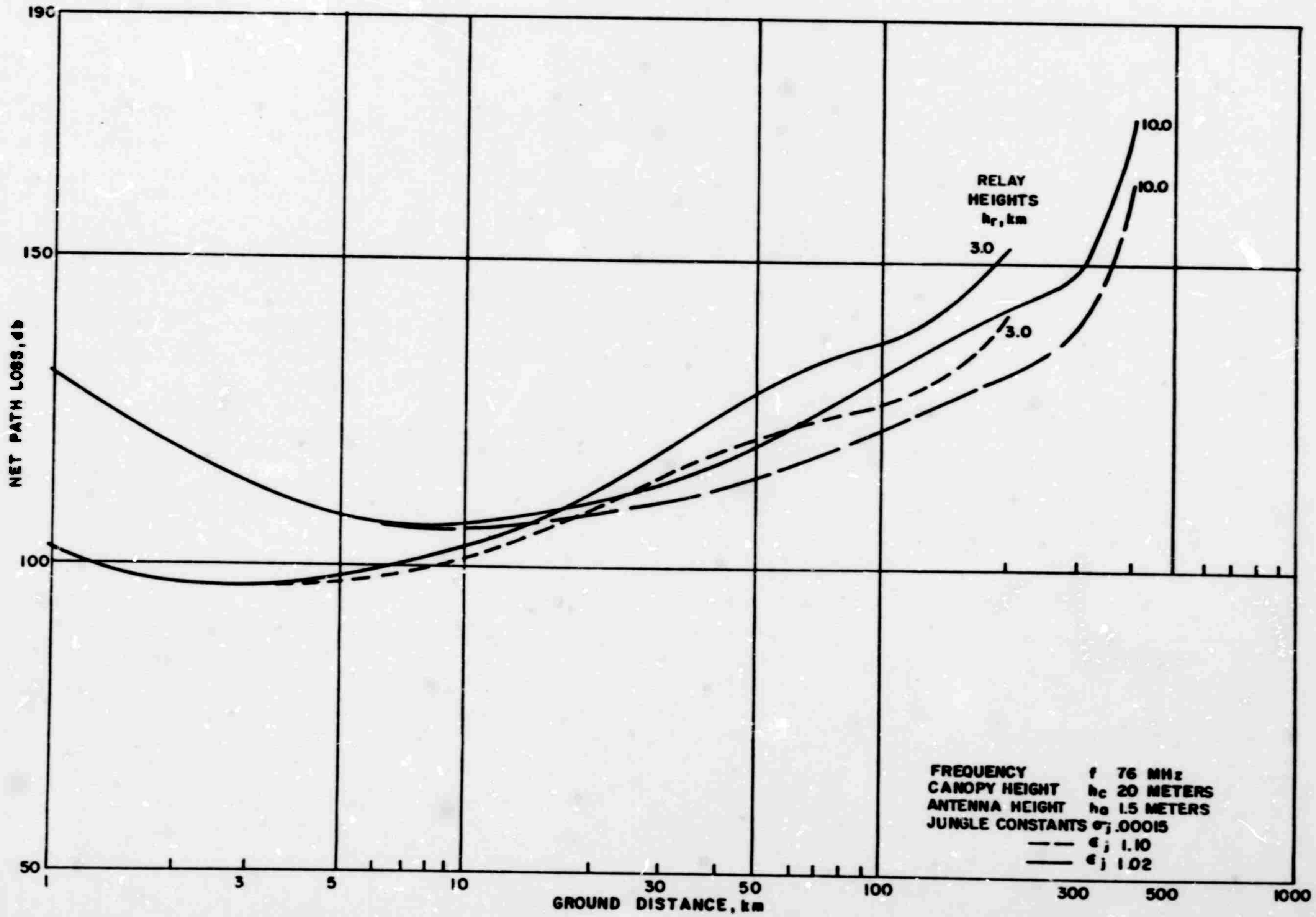


Figure 3-16. Path Loss vs. Ground Distance with Variations in Permitivity (76 MHz Frequency)

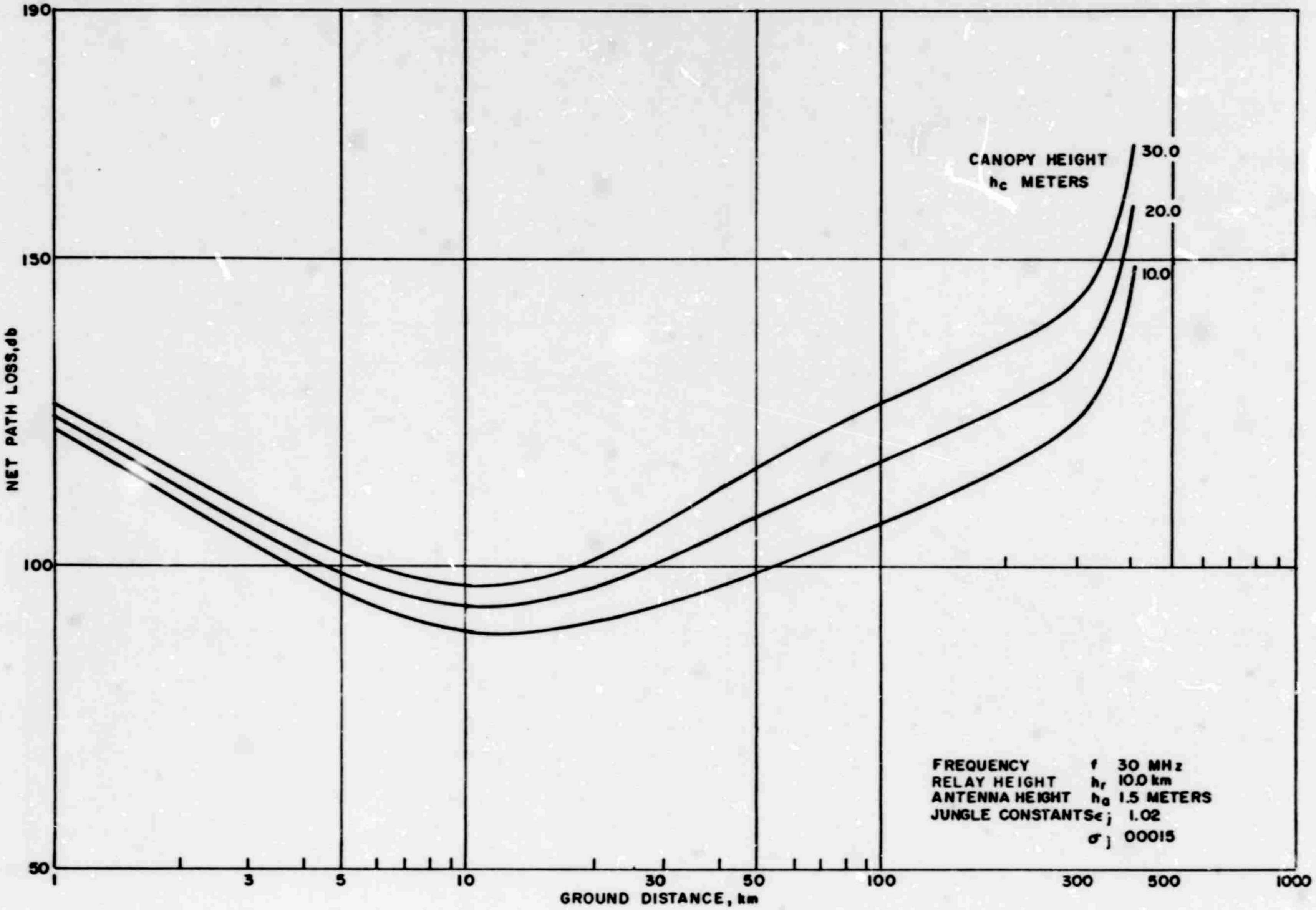


Figure 3-17. Path Loss vs Ground Distance with Variations in Canopy Height (30 MHz)

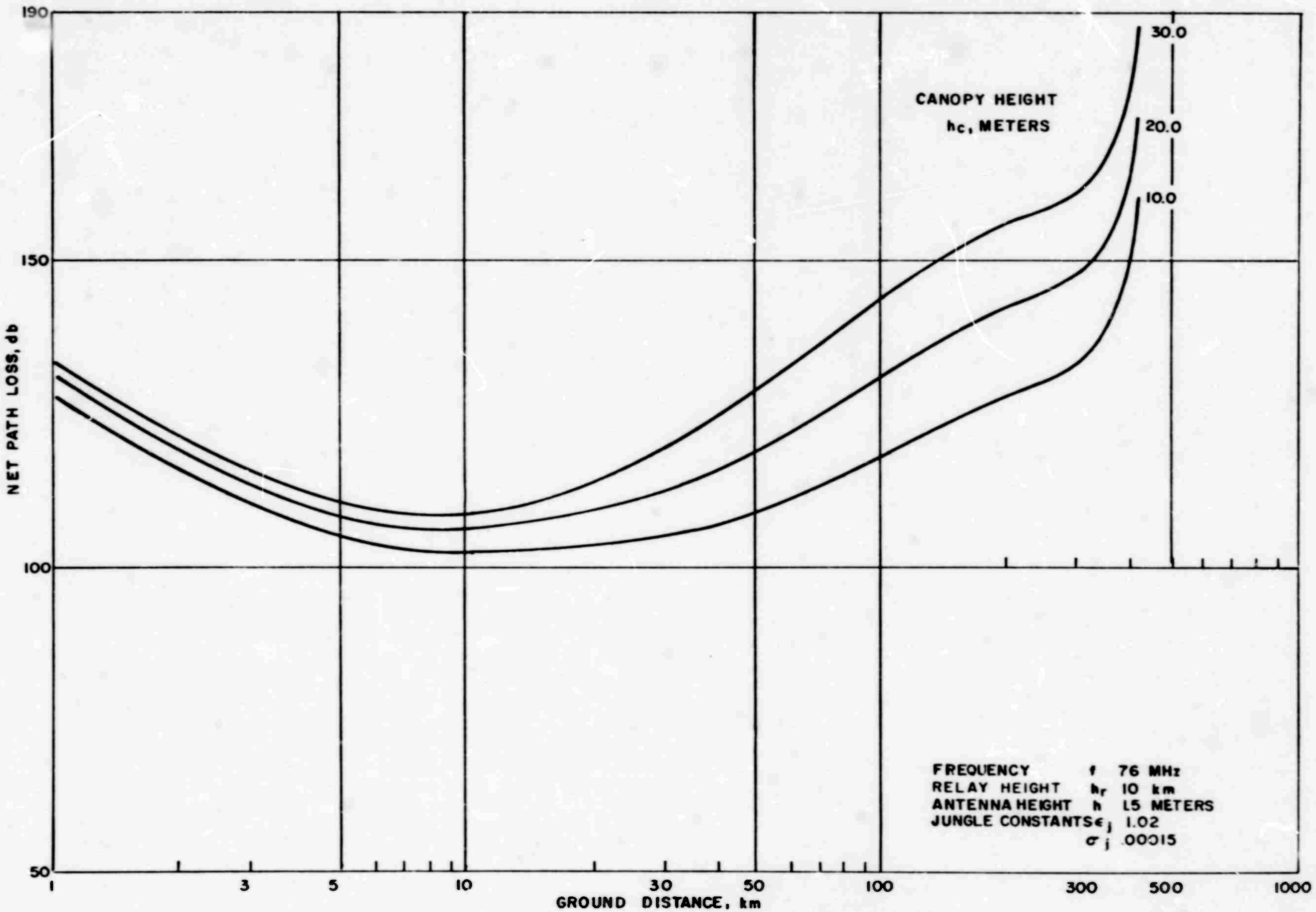


Figure 3-18. Path Loss vs Ground Distance with Variations in Canopy Height (76 MHz Frequency)

to use a highly directional antenna on the platform. In addition, it is possible that the tactical unit requiring the relay support may not be in a position to aim the ground antenna; and, it is conceivable that the relay could be near the horizon.

From the foregoing it would appear that the antennas for use on the airborne platform should be omni-directional and that ground antennas should have relatively broad azimuthal patterns. Since the greatest path loss is encountered at low elevation angles, gain in the elevation plane might be useful with the cosecant-squared type of antenna pattern used in some radar applications.

3.3.2.6 Allowable Path Loss

An alternate presentation of the data may be useful in visualizing platform height-system gain tradeoffs. Here, required relay altitude is plotted against ground distance parametrically in allowable path loss. Curves of this type are presented in Figures 3-19 and 3-20. The curves are plotted for a canopy height h_c of 20 meters, σ_j of .00015 mhos and ϵ_j of 1.02 at frequencies of 30 and 76 MHz.

It should be noted that these curves (3-13 through 3-20 do not include the variational component, which defines the additional path loss for a particular fraction of time.

3.3.3 Propagation Variability

3.3.3.1 Within the Jungle Canopy

Path losses computed for propagation through the jungle are median values, based upon average electrical parameters of the jungle. In actual fact, there are discontinuities (such as tree trunks and branches) and voids large compared with a wavelength, which result in substantial spatial variation in received signal with small displacements about any location. Further, the assumption of a smooth (compared to a wavelength) interface between the jungle and air breaks down with increasing frequency. Sachs, (ref. 3.3-5, FIGURES 19, 20) presents distributions of differences between predicted and measured path losses between two antennas immersed in the jungle. These curves are Gaussian in shape and display the following characteristics:

Frequency Range, MHz	Median Error, db	Standard Deviation, db
6 - 100	-1.5	6.0
250 - 400	-4.0	10.5

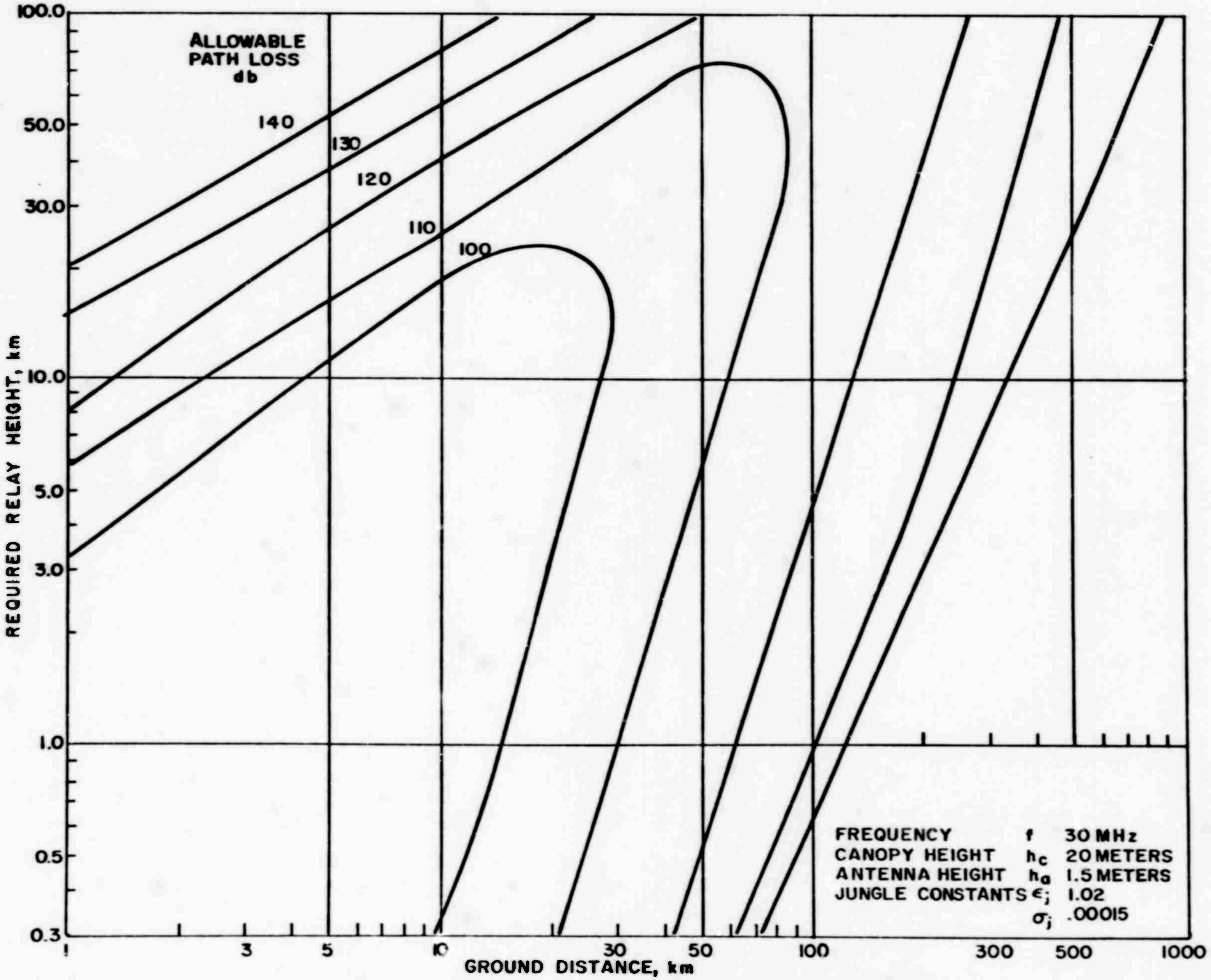


Figure 3-19. Required Relay Height vs. Ground Distance for a Specified Allowable Path Loss (30 MHz Frequency)

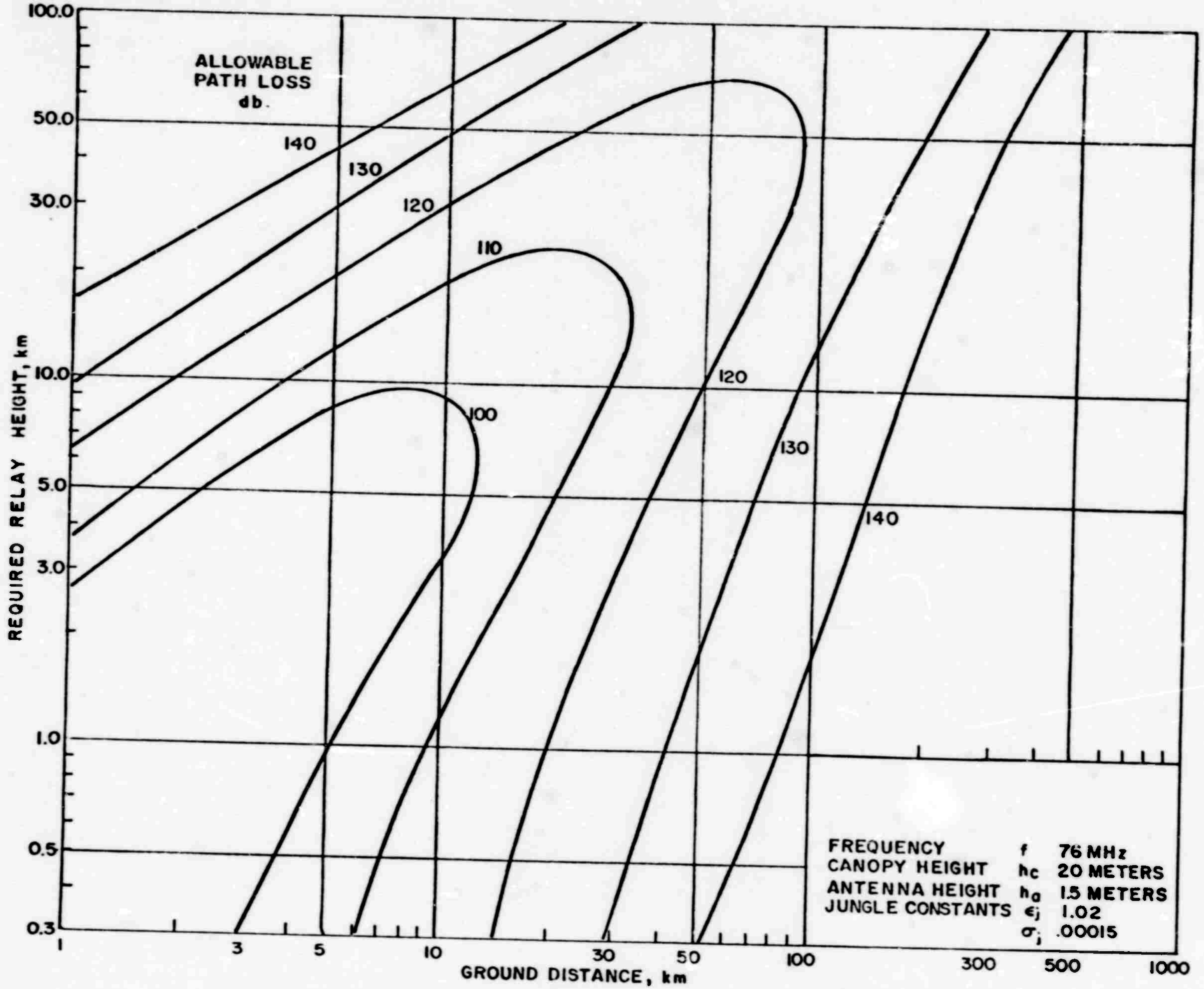


Figure 3-20. Required Relay Height vs. Ground Distance for a Specified Allowable Path Loss (76 MHz Frequency)

Somewhat more directly applicable data are available, however, for the VHF ground-to-air case. An SRI report on measurements between an aircraft and a ground transmitter through dense Eucalyptus foliage provides some directly-scaled loss statistics (ref. 3.3-10). Figure 3-21, which is replotted from FIGURE 26 (c) of ref. 3.3-10, shows the distribution of measurements of path loss exceeding the median.

As previously noted, SRI has performed a series of measurements of air-to-ground propagation in Thailand using a helicopter-towed XELEDOP transmitter, and is currently engaged in analysis of the resulting data. When available, these data will provide a further basis for the variations of path loss to be expected.

In the absence of these measurements, the distribution of FIGURE 3.3-13 can be used to determine margins necessary to assure a specified probability of service for a one-way link. For a 90 percent probability (probably adequate in view of the possibility of a avoiding deep nulls by small movements of the antenna) it can be seen from Figure 3-21 that a 15 db margin is required; for 99 percent, 20 db becomes necessary.

In a link containing a relay, if the relay involves a limiting process, the signal power will remain constant at the demodulator inputs while the noise powers add for the uplink and for the downlink. By convolving the single link loss distribution of Figure 3-21 with itself (using a numerical process employing a Stieltjes diagram*) the distribution of the signal variations for two tandem links with equal median power may be obtained. Since the signal level is held constant, this distribution (Figure 3-22) may be used to determine the margin required on each of two tandem links for a particular probability of the link being satisfactory. For example, if the desired reliability is 90% then a margin of 9.5 db must be provided for each link of two tandem links.

Both of these curves (Figures 3-21 and 3-22) should be revised when the data from the SRI airborne XELEDOP tests becomes available.

3.3.3.2 Variability for UHF Multichannel Communication

In this section, the multichannel relay is assumed to be free of the jungle canopy. The slant range to the platform, as shown in Figure 3-10 has been computed for different elevation angles and platform altitudes. While

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* By Stieltjes diagram is meant, for random variables x, y, a planar plot on x-y coordinates of equal Stieltjes probability measures $dP_1(x)dP_2(y)$. This unit measure is usually taken as 1% but may, of course, be taken larger or smaller to suit circumstances and convenience.

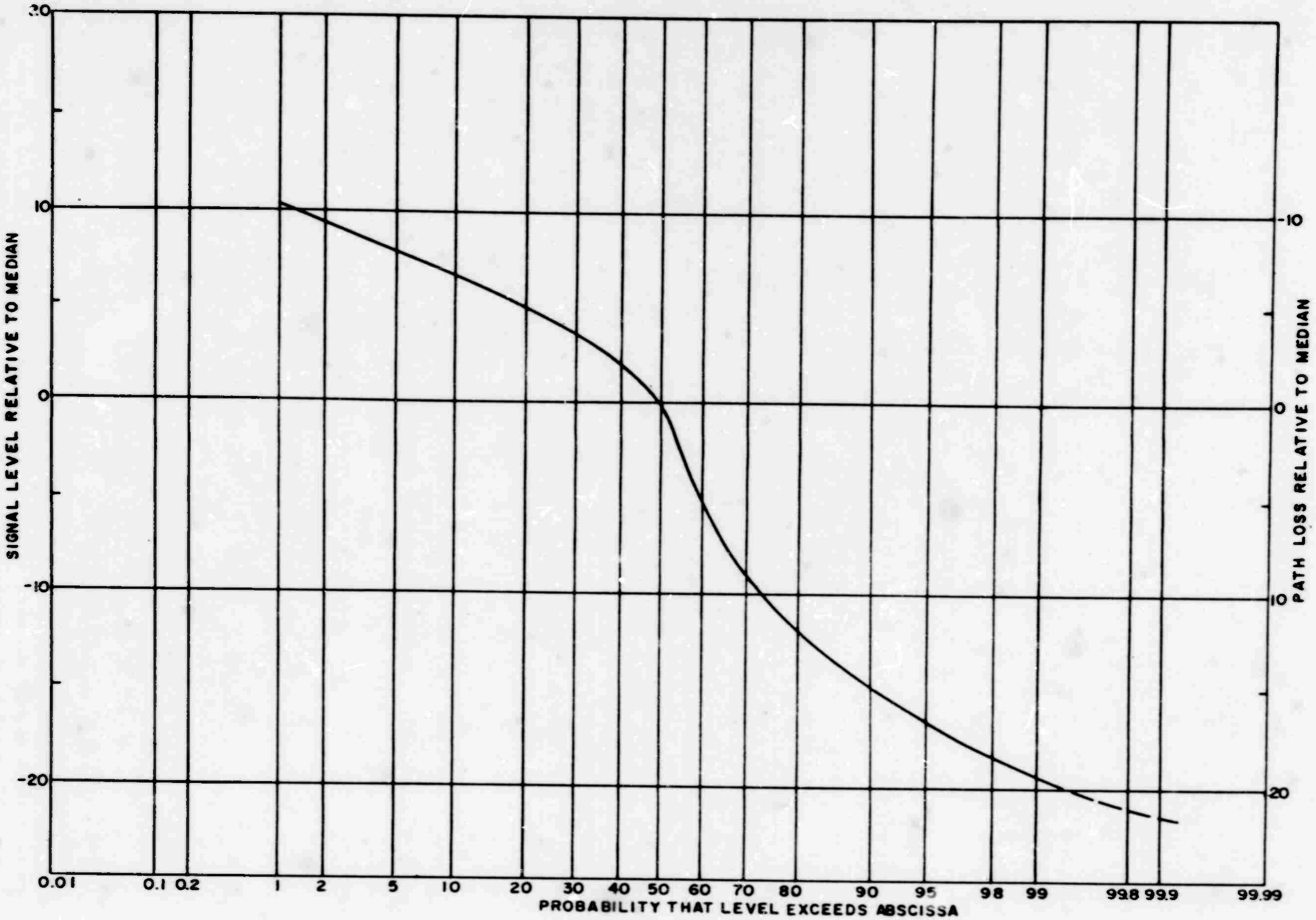


Figure 3-21. Probability that Air-Ground Path Loss to a Site in Jungle will Exceed Calculated Median

Figure 3-22. Probability that Power Sum Exceeds Ordinate, or Power Margin for Specified Probability of Satisfactory Tandem Links

the range increases considerably at angles below 1°, the probability of outage due to earth bulge fading increases significantly. At these angles an additional margin is required to provide the desired long-term reliability. Lacking detailed meteorological data for specific paths, the CCIR procedures for earth space links are used. A frequency of 2 GHz has been chosen as typical for this application. Figure 3-23 indicates that an allowance of 12 db is required for a median level reliability of 99% at a zero takeoff and a slant range of 300 km. Allowances for long-term effects are sharply reduced if elevation angles significantly below .03 radians (1.7 degrees) are not used. For angles above this, a monthly median reliability of 99% is obtainable at a slant range of 300 km with a margin of 6 db.

The preceeding analysis has demonstrated that the effective communications range of the relay is a function of platform altitude. For a given slant range, the required long-term margin is less at the higher altitudes or angles. Exclusive of jungle considerations, the total path loss, including allowances for both long and short term fade margins, is shown in Table 3-1. These values have been calculated to include the effects of platform altitude, but exclude antenna gain considerations. The required fade margin for 99.99% interference reliability can be reduced by some 20 db by the use of frequency diversity with a 5% frequency separation. Space diversity may also be used to improve the situation.

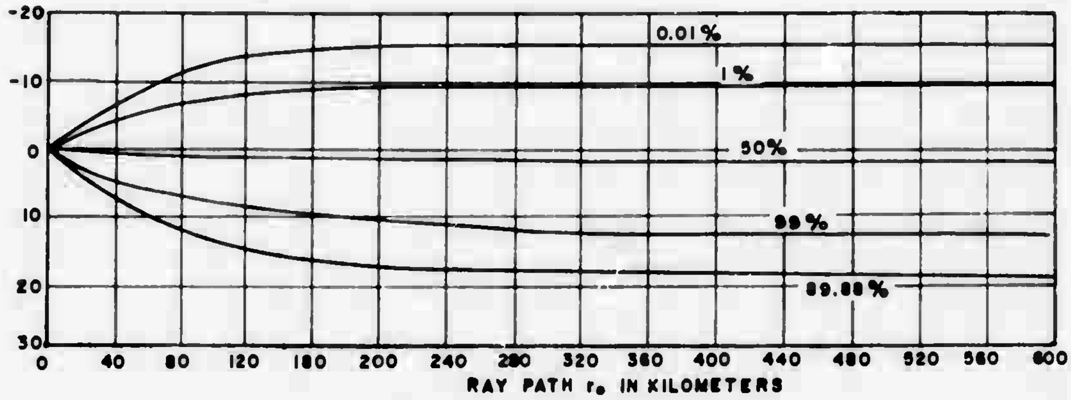
3.3.4 Propagation Implications for Relay Design

3.3.4.1 Introduction

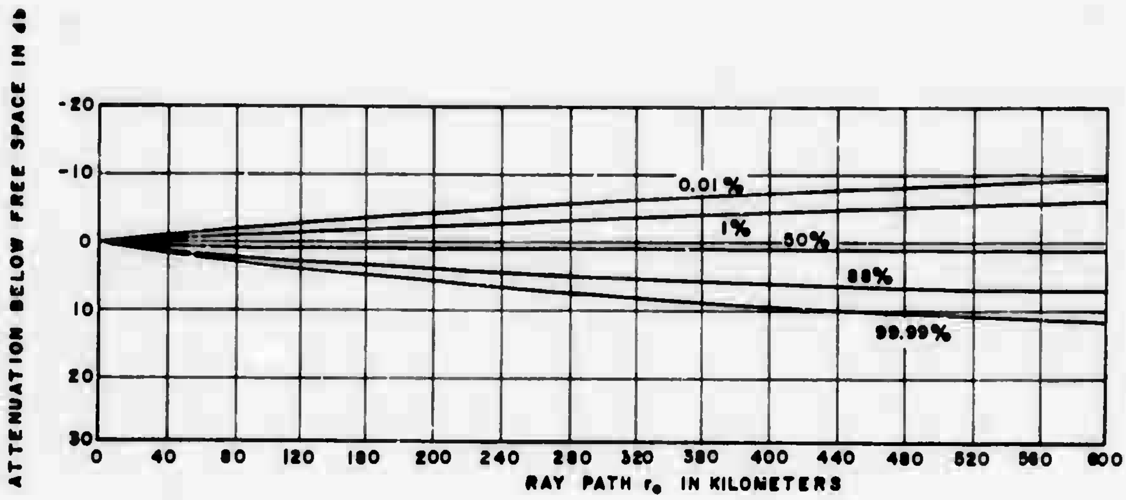
The primary reason for examining the air-to-ground path loss is, of course, to define the necessary relay power output, receiver sensitivity, and antenna gain for a given communications requirement based on analysis of the tactical problems. Conversely, for bounded relay parameters, the range for a given probability of satisfactory service may be determined.

Those relay configurations in which broadband receivers (covering more than one RF channel) are used will be exposed to signals of different levels, depending on the range and jungle absorption or re-radiation of particular emitters. It is necessary to evaluate the distribution of amplitude differences as a means of determining relay dynamic range requirements.

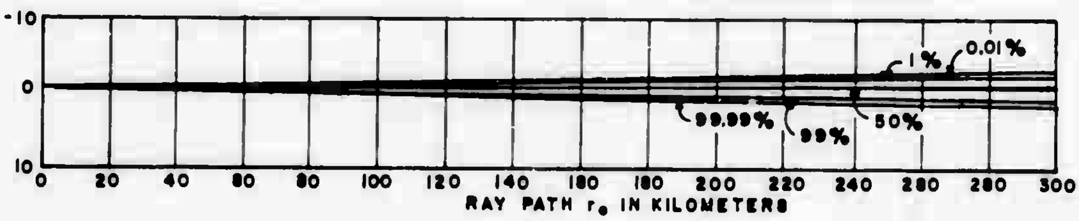
In increasing the range of tactical radio sets, the relay will extend the area over which co-channel interference will be experienced. This is an inevitable price to be paid for increasing the range, but must be evaluated to determine the extent to which frequency allocations must be changed. The interference analysis is also applicable to the evaluation of jamming susceptibility.



Elevation Angle = 0 RADIANS (0°)



Elevation Angle = 0.03 RADIANS (≈2°)



Elevation Angle = 0.1 RADIANS (≈6°)

NO ALLOWANCE HAS BEEN MADE FOR GROUND REFLECTION

Figure 3-23- Standard CCIR Propagation Curves for Earth-Space Links-2 GHz

Table 3-1. Path Loss for Propagation Reliability - 99.99%*

Slant Range (km)	Free Space Loss (db)	0.3 km	Platform 1 km	Altitude 3 km	Altitude 10 km
10	118.6	118.6/156.6	118.6/156.6	118.6/156.6	118.6/156.6
30	128.0	134.0/172.0	129.0/167.0	128.0/166.0	128.0/166.0
50	132.6	142.1/180.1	138.1/176.1	133.3/171.3	132.6/170.6
100	138.6	-----	152.1/190.1	141.6/179.6	139.6/177.6
300	148.0	-----	-----	-----	160.0/198.0

*Values shown include long-term margin and are without/with the 38 db margin for short-term non-diversity multipath protection.

3.3.4.2 Service Range

3.3.4.2.1 VHF-FM Service Range

While the relay transmitter power output is much more readily increased than the transceiver power output, it is still subject to limitations due to interference and platform power supply restrictions. The uplink from a transceiver to the relay is the limitation on overall system performance, since the relay receiver noise temperature is determined by external noise at the 30-70 MHz frequency band. Directive antennas at either the ground or the relay do not appear to be practical from a physical size standpoint, and transceiver power output is limited by battery weight and life.

The following factors must be considered in estimating the total path loss, and thus the range for a given equipment configuration:

a. systematic loss component (slab model)
b. jungle loss variability
c. platform antenna pattern variability
d. atmospheric variability
e. loss due to electrically short antennas.

Of these factors, (a) has been analyzed earlier in this section of the report, (b) and (d) are combined in the experimental variability factor, and (c) has been neglected for the time being. The PRC-25 3-foot whip antenna is less than a quarter wavelength at all operating frequencies, and the 10-foot whip is a quarter wavelength at 24.6 MHz. The possible variety of antenna patterns available at various frequencies, heights above the ground, etc., make the antenna gain indeterminate, so the half-wave dipole pattern has been assumed in the computation of path loss contours, and the antenna's lobe structure has been absorbed into the variability terms.

In regard to the variety of antenna patterns, it may be noted that pack-set operators often bend the 3-foot whip forward across their shoulders or tuck the end of the whip under their belts to reduce their visibility to the enemy.

If the repeater-receiver sensitivity is equal to that of the PRC-25, a signal level of -113 dbm provides a 10 db audio signal-to-noise ratio. We will assume the uplink and downlink to have identical parameters. With an output power of 1 watt (+30 dbm) at 76 MHz, and a -113 dbm minimum received signal, the path loss must be less than 143 db. This budget assumes equal median signal-to-noise ratios for the uplink and downlink, with a median signal-to-noise ratio of 10 db at the receiver. The variability factor indicates that a margin of 9.5 db must be provided on each link to give a net 90% probability of a 10 db or greater signal-to-noise ratio. Subtracting the margin requirement from the 143 db "threshold" path loss leaves 133.5 db as a per-link allowable path loss. If the uplink and down-link path loss medians are not equal, the margin should be re-evaluated.

Figures 3-24 and 3-25 show the probability that the received signal exceeds a specified path loss through the jungle canopy at various ground distances. These curves were prepared for a 3 km relay height and a jungle canopy height of 20 meters. At 76 MHz, a 143 db threshold is shown on Figure 3-25 to yield a ground range to 130 km for 50% probability. The distance decreases to 50 km as the requirements are raised to 90% for the same allowed loss. At a given ground distance the probability that the received signal exceeds a specified loss increases significantly as the allowed loss is increased. That is, Figure 3-25 illustrates that an allowed loss of 143 db yields a 60% probability at 100 km; however, increasing the power 10 db so that the allowed loss is 153 db increases the probability to 95%. Note that the ranges are computed from the pack-set terminal to a point below the relay, so that the overall circuit length may be as much as twice this amount. An increase in canopy height or in permittivity will reduce the reliability for a given range.

3.3.4.2.2 UHF AM Service Range

A UHF relay-augmented tactical network would not be feasible in an area characterized by jungle foliage, but may be useful in grassland or desert areas. The applicability of the previously employed propagation model to describe UHF propagation is questionable, so in the example to follow, we have simply computed the free-space path loss, and assumed isotropic antennas. The assumed terminals are AN/PRC-66 transceivers, and the relay is the AN/ARC-97. Both of these equipments are described in more detail in Section 3.4 of this report. The ARC-97 receiver is rather insensitive (5 μv for 10 db S+N/N) so the up-link limits system performance. The PRC-66 output power is 2 watts, +3 dbw, so a maximum loss from transmitter to receiver of +3-(-123)=126 db can be tolerated. This corresponds to a free space range of 212 km at 225 MHz or 119 km at 400 MHz. No allowance has been included for platform antenna pattern irregularities, etc. While military operations in open country might be expected to be spread over larger areas, the relay range seems to be adequate for many operations.

3.3.4.2.3 Multichannel UHF Relay Service Range

The FM multichannel relay circuit is assumed to use terminals with line-of-sight clearance to the relay platform. The range example concerns a relay link for 12 voice channels. The AN/ARC-89(V) receiver (the AN/ARR-71) recommended for the interim time frame multi-

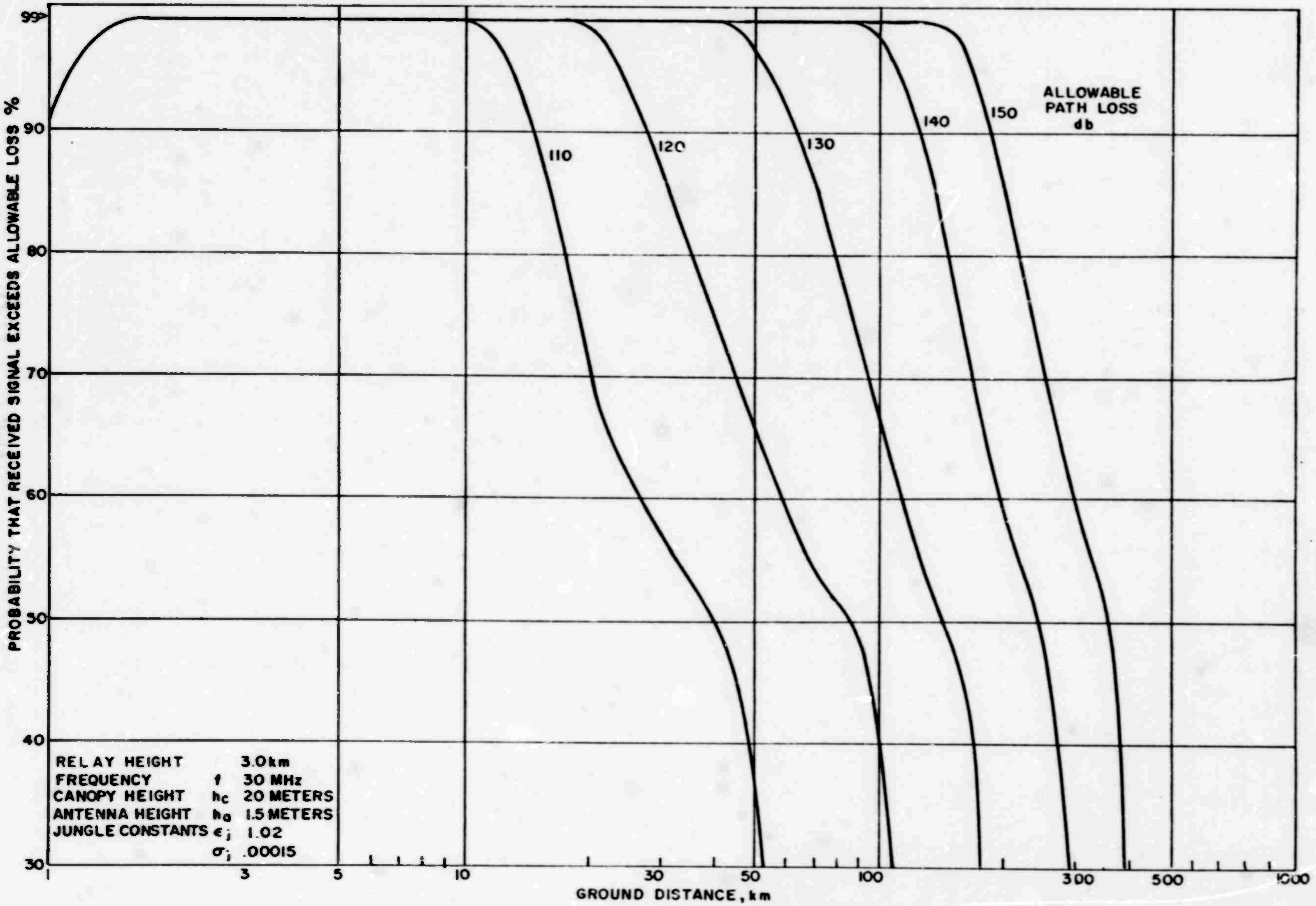


Figure 3-24. Service Range for Specified Allowable Path Loss (30 MHz Frequency)

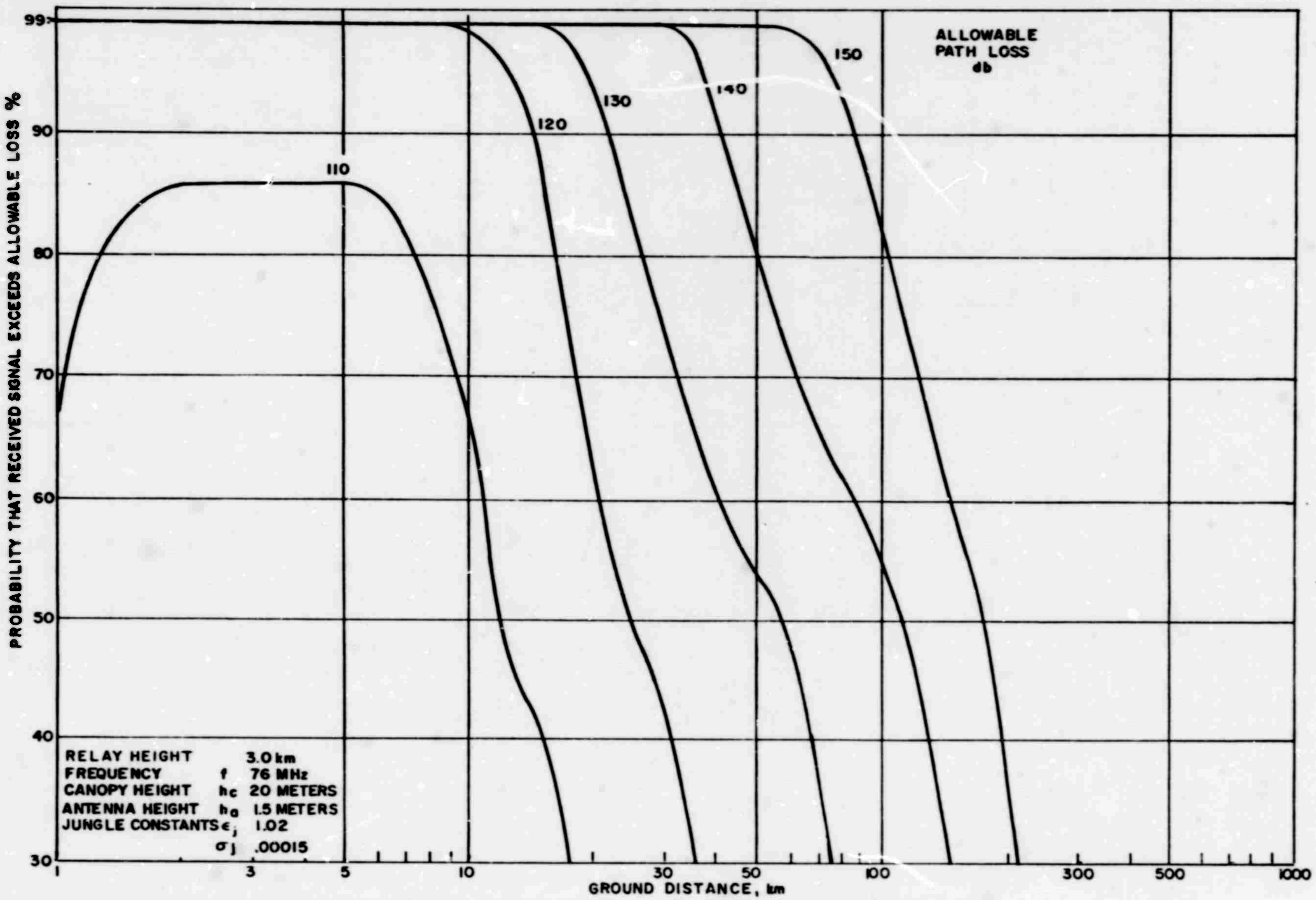


Figure 3-25. Service Range for Specified Allowable Path Loss (76 MHz Frequency)

channel relay is specified to give less than 38 dba0 intermodulation distortion, so setting the voice channel thermal noise equal to this, we require an unweighted test tone to noise ratio of 44 db. The rms test tone to thermal noise ratio in 3 kHz is given by:

$$S/N = (C/n_o)\ (1/b)\ (\Delta f/f)^2$$

where S = rms test tone level

N = rms noise power in 3 kHz

C = received carrier level

n_o = noise power density

B = IF bandwidth

b = channel bandwidth = 3 kHz

Δf = rms test tone deviation

f = top baseband frequency

The ratio $\Delta f/f$ is the rms modulation index, which is specified as unity for the AN/ART-47.

The noise power density may be computed from the receiver noise figure, 8 db, plus an allowance of perhaps 2 db for diplexing filter and feed line losses. The noise power density is given by

$$n = kT$$

where n is the power density, watts/Hz

k is the Boltzman's constant, watts/Hz/$^{\circ}$K

T is the noise temperature, $^{\circ}$K

The net noise figure of 10 db corresponds to a noise temperature of 2600° K, or 34.1 db above 1°K. Boltzman's constant may be given as -228.6 dbw per $^{\circ}$K per Hz, so the noise power density is -184.5 dbw per Hz.

Returning to the equation above for the test tone to noise ratio, which may be expressed in decibels as:

$$S/N = 44 = C + 184.5 - 34.8 = C + 149.7$$

$$C = -105.7 \text{ dbw}$$

A concurrent condition is that the carrier to noise power ratio in the receiver

IF bandwidth, 500 kHz, be above threshold, so

$$C/N_{if} = -105.7 + 184.5 - 57 = 21.8 \text{ db}$$

which is safely above threshold.

At 400 MHz, the carrier level of -105.7 dbw gives a range of:

Range		Effective Radiated Power (ERP)
11.5 km	for	1 watt
36.3		10
115		100
363		1,000

where the power requirements may be reduced or the range extended by means of antenna directivity. A modest 10 db antenna gain at the ground (corresponding to a half-power beamwidth of roughly 45°) would supply additional fading margin or range.

3.3.4.3 Distribution of Signal Levels

In those relay configurations requiring the use of multichannel amplifiers, the distribution of signal levels will determine the dynamic range requirements of the relay. With equal channel spacing in the frequency spectrum, intermodulation products will fall at the same intervals. Channel occupancy is variable, so whether a particular intermodulation product is produced or whether it falls in an occupied channel is probabilistic.

The distribution of relay users within the service area must be modified by the previously derived path loss relations to obtain a distribution of received power levels. A further correction required is to convolve this distribution with the distribution of path loss variability. The resulting distribution will give estimates of the percentage of signals occuring within specified power ranges, for a given relay altitude and set of jungle parameters.

Looking at the problem in a more realistic way, the maximum signal power at the relay will be from transceivers operating in clear areas more or less below the relay. Since vertical dipoles are assumed in the path loss computation, excessively high loss values are associated with this region. In practice, neither the transceiver whip nor the relay antenna will be quite vertical, and there will be some depolarization by re-radiation from the foliage, so there will be relatively little attenuation due to the antenna patterns. Free space attenuation for a relay altitude of 3 km, at 76 MHz, will be approximately 80 db, compared with the path loss of 133.5 db allowed for minimum signal quality in paragraph 3.3.4.2 above. A range of signal power of the order of 50 db is thus indicated. Accordingly the relay should be capable of handling signals which differ in level by at least 50 db.

3.3.4.4 Interference

There are several categories of interference to be considered in high altitude relay networks:

1. Existing interference to VHF Communications from various radio services.

2. Interference introduced by high altitude relays by virtue of extended range.

3. Self-interference in ground-relay-ground system.

It was noted at the ARPA/AGILE Colloquium (March, 1967) that VHF frequency assignments in Viet Nam are rather extensive. Tactical VHF equipment operates in a relatively narrow portion of the nominal 30-76 MHz frequency range, and frequencies are reused by alternate Corps areas. It is reasonable to expect that this situation will obtain in other limited warfare or counterinsurgency operations. Interference from taxi and police radios, television broadcast stations, and other sources will be experienced almost anywhere. The high altitude relay receiver is particularly vulnerable to long-range interferences. The only alternative is the availability of a number of channels, such that interference may be avoided. Protection through shaping of the antenna pattern may be feasible at UHF or microwave frequencies, but the platform dimensions are comparable to a wavelength in the 30-76MHz range. The presence of external interference, as in the case of jamming, provides an argument against the use of broadband amplifiers in the receiving side of the relay.

In the same manner, the interference between frequency assignment repetition areas is increased by the relay transmitters, and relay platforms may have line-of-sight paths between one another.

It may be useful to compare the ground-to-air path loss computation with the free space loss between two relays at 3 km altitude. Suppose that the two relay platforms were separated by 100 miles (161 km). At 76MHz, the free-space attenuation between them would be approximately 114. db, while the loss to a ground station at 50 miles (80.5 km) range would be 134 db, (from Figure 3-14) with a 50% probability of exceeding this loss. Use of the same channel at the two relays is obviously impossible.

Use of adjacent channels would depend on the selectivity and overload characteristics of the relay receiver, and may serve to define requirements for these characteristics.

This situation indicates that the number of relayed channels should be as small as possible, with maximum sharing of such channels between relay users. Relays should be used only when necessary for particular subscribers, as indiscriminate augmentation of FM nets is wasteful of channels, and F_1-F_1 relays may introduce multipath interference. This results when the signal received from the relay and the signal received directly are of comparable amplitude. Subscribers with otherwise satisfactory circuits may find the circuit unusable when a relay is activated on the channel. This an argument against F_1-F_1 relay operation.

Interference problems within the relay include intermodulation in common amplifiers and interference in relay receivers due to relay transmitters. The first category of interference is minimized by controlling the power of individual up-link signals, either by controlling the ground transmitter power output or by separate AGC channels in the relay. Spurious responses in the relay receiver may be minimized by proper receiver design. The F_1-F_1 switching relay has the advantage of synchronized switching, so that all receivers or all transmitters are on at any instant.

3.3.4.5 Jamming Considerations

While the HARR study has not required detailed consideration of jamming, the effects of jamming on relay design and application should be discussed.

Contemporary guerrilla tactics are aimed at decentralized military operations requiring minimal real-time communications. Counter-guerrilla operations, on the other hand, have depended heavily on inter-unit and intra-unit radio communications for the coordination of operations. The guerrilla force may therefore use broadband jamming at a minimal expense to its own operations, provided that power requirements are consistent with the mobility needed to avoid destruction of the jammer and with portable power sources. As guerrilla tactics have proved difficult and expensive to counter, it is logical to assume that this form of warfare will constitute a large fraction of future limited warfare and counterinsurgency operations.

Since the supply of weapons for guerrilla forces is often from countries with sophisticated electronic technology, the jamming equipment encountered may be as sophisticated as available relays or AJ equipment. It is not clear what action would be taken against a jammer operating outside the boundaries of countries nominally involved in the war.

For the relatively unsophisticated relays we have discussed for use with VHF-FM single channel pack sets, several sorts of jammers or combinations of these types may be envisioned:

1. CW Jammer - A continuous signal at the carrier frequency of one or more relay channels.

2. Modulated Jamming - Voice, noise, or tone pattern modulators applied to one or more relay channels.

3. Barrage Jamming - Broadband noise jamming of one or more relay channels.

4. Pulse Jamming - Keying of a carrier signal centered among several relay channels.

A classified report by the Research Analysis Corp. (ref. 3.3-11) compares quantitatively the effectiveness of these techniques.

Since the pack-sets' ERP (referred to the outside of the jungle carrier will be less than 1 watt, we may say as a rough approximation that the ERP from the jammer must be 1 watt plus the additional loss on the path from the jamming transmitter, to jam any single channel from the ground. At a platform at 10,000 feet altitude the maximum signal from a 1 watt ERP pack-set is -72 dbw (30 MHz, isotropic antennas). Each relay channel could then be jammed by 10 w. ERP at 10 km slant range, or 1000 w. ERP at 100 km. If the relay were at an altitude of 100,000 feet, the maximum pack-set signal would be -92 dbw, and jammer requirements would be 100 w. ERP at 100 km. These ranges may not be reasonable for particularly rough earth profiles between the jammer and the relay. For a smooth earth, (radius corresponding to N_s = 360, typical of Viet Nam) the horizon distance would be 244 km at 10,000 ft. and 772 km at 100,000 ft.

The jammer may be able to use considerably more antenna gain than is possible for an omnidirectional pack-set antenna, so that the jamming transmitter power required may be a good deal lower than the ERP indicated above. Since the slant range is nearly the same from a synchronous satellite to any point where the satellite is above the horizon, a jammer needs no more power than the 1 watt ERP per channel of the desired transceiver signal.

The foregoing discussion relates to relays with single channel selectivity. If a broadband relay is employed, with peak-power capability adequate to provide satisfactory intermodulation performance, the jammer can operate in two ways. Either he may jam one or more channels with discrete jamming signals or noise, or he may gain an additional advantage (beyond the J/S ratio at the relay receiver) by saturating the relay. Unless the entire relay passband is monitored, the presence of a jamming signal may be difficult to identify from the ground.

The susceptibility to jamming must be considered a weak point of broadband relays. At the expense of added relay complexity and less flexibility of channel assignment, the separate channel approach offers some protection against narrow-band jamming modes and provides up-link power control. In either case, broadband monitoring facilities should be provided to identify jamming so that appropriate countermeasures may be initiated.

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3.4 RELAY APPLICATION OF CONTEMPORARY EQUIPMENT

3.4.1 Equipment Configurations

In applying contemporary equipment to the initial or interim time frame relay requirements, it is anticipated that only limited modifications or replacement of tactical radio equipment can be undertaken. Similarly, the components of the relay package itself will have to be available from military inventory or will have to be substantially production status military or commercial hardware. A limited amount of development effort for interface and control may be undertaken for either the initial or interim time frames.

In the following paragraphs, the available equipment will be reviewed, and its suitability for relay application considered. There is a limited number of equipments designed specifically for relay service, and no one equipment is capable of meeting the requirements of relaying several simultaneous channels for FM tactical networks. We have therefore considered a multi-transceiver assembly, of either the frequency translating (F_1-F_2) or common frequency switched (F_1-F_1) variety, similar to the block diagrams in Figures 3-2 and 3-4.

The F_1-F_2 relay is constrained to use one moderately narrow (perhaps 10%) frequency range for up-link operation, and another such range separated by another 10% for transmitting. This arrangement permits use of a common antenna on the airborne platform, by means of a passive receiver and transmitter multicoupler and diplexing filter. Experience with the AN/PRC-25* suggests that it will be necessary to shield separately each transceiver in the relay package, since stray radiation from the battery and interconnecting cables produces a welter of spurious responses. The rf sensitivity of the battery cable indicates the need for caution in decoupling the common power supply shown in Figure 3-2. The spurious output/response situation has been improved in the later AN/PRC-77.

The corresponding F_1-F_1 relay package shown in Figure 3-4 is predicated on the use of low-frequency (e.g. 10 Hz) commutation. This configuration requires the development of a multi-channel time delay to

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* Measurements by Page Communications Engineers, Inc. showed that 236 receiver channels out of 420 were interfered with by a nearby AN/PRC-25 transmitting at 33.05 MHz. The PRC-25 operator's manual (ref. 3.4-2) indicates only 14 such responses. The need for care in shielding units employed in relay evaluation can not be overemphasized. (See Appendix, Section 5-1).

store alternate 50 ms samples from each relay channel. For the interim time frame requirement, this may probably be realized most easily by a multichannel magnetic drum or tape loop. Digital storage requires a commutator, A-D converter, perhaps 1800 bits of storage capacity per relay channel, a D-A converter, and a decommutator. Storage requirements are based on 6 bits x 6000 samples per second x 50 ms/1 sec. Some further reduction in quantizing levels or sampling rate may be possible before a noticeable degradation in intelligibility results. Since the channels are switched synchronously, all receivers are on simultaneously, or all transmitters. The problems of shielding and isolation are therefore minimized, and the relay package itself does not constrain channel selection. Some constraint is to be expected from the platform antenna.

For application in manned platforms, the use of a relay switchboard operator appears to be desirable, on the basis of the discussion in Paragraph 3.2.2. Such a switchboard was indicated in Figures 3-2 and 3-4 as supervisory equipment. The operator has the capability of changing relay channel frequencies or of assigning relay channels on the basis of message priority. He may also monitor traffic to detect unauthorized use of the relay or jamming.

In a multichannel UHF or SHF relay application, the relay platform would not necessarily perform any demodulation of up-link information, so the only contact between the ground and relay platform itself would be a supervisory channel, probably at UHF, to coordinate platform operational functions.

3.4.2 VHF - FM Relay Equipment

3.4.2.1 General

The following paragraphs review available equipment for application in the context of 30 to 76 MHz tactical FM network relaying, where associated ground terminals are AN/PRC-25 or equipments of the same general nature. The equipment description is summarized in Table 3-2. The weight, bulk, and power consumption, and cost of multiple-channel combinations of units will be roughly proportional to the number of relay channels, although some economics can be realized in the area of equipment common to all units.

The equipment status is described as developmental, production, Standard A or Standard B as applicable. The Standard A and B designations are defined as follows (ref. 3.4-7):

1. Standard A: Items that have been adopted as suitable for U.S. Army use, which are acceptable as assets to meet

VHF - FM Equipment Type	Status	Weight (less battery) Lbs.	Volume Ft.^{3}	Power Input (XMT) Watts	Power Out Watts	Freq. Range MHz	Tuning Increment kHz	Rcvr. Sens. μv.	Remarks
AN/PRC-25	STD-A	13.6	0.25 (2)	15.7	1.0-1.5	30-76	50	0.5	
AN/PRC-77	PROD	13.2	0.25 (2)	9.7	1.5-2	30-76	50	0.5	Improved PRC-25
AN/PRC-70	DEV	14	0.2	132	40	2-76	1	0.4	AM, SSB, FM, CW
AN/PRC-72	DEV	12 (1)	.43 (2)		6	38-50	1000		
AN/PRR-9	DEV	0.5 (3)	12 in^3		-	47-57	-	0.5	Single channel receiver
AN/PRT-4	DEV	1.1 (3)	25.4 in^3	1.44	0.45	47-57	-	-	2 channel transmitter
AM/4306	PROD	8	.145	60	25	30-76	-	-	Power Amp. for PRC-25/ PRC-77
AN/ARC-44	STD B	39		250	8	24-51.9	100		
AN/ARC-54	STD A	25	0.5	210	10	30.69.5	50	1.2	
AN/ARC-114	DEV	8	.09	60	10	30-70	50	0.6	
AT-430	DEV	20	0.3	132	40	2-76	1	0.4	AVCO Corp. (See PRC-70)

NOTES:
(1) Estimated
(2) Volume includes battery pack, transceiver itself is approx. 1/2 of total
(3) Including battery

Table 3-2. VHF - FM Equipment

operational requirements, authorized in equipment documents, and described in published adopted item lists.

2. Standard B: Items which have limited acceptability to fill operational requirements. These items are normally used and issued as a substitution for STD A items.

These ratings are continually in a state of flux, and items listed in one category may have progressed to another.

3.4.2.2 AN/PRC-25

The PRC-25 (ref. 3.4-1) is a lightweight pack-set radio which tunes from 30 to 76 MHz in 50 kHz synthesized steps. The receiver and transmitter are tuned simultaneously. An adjustable frequency control detent provides two preset channels. The unit is solid-state except for the transmitter output stage. A tone-operated squelch provides receiver quieting.

The AN/PRC-25 transceiver is intended to function as a F_1-F_2 relay terminal by connecting two PRC-25 units with the MK-456/GRC interconnecting cable. The squelch of one receiver activates the transmitter in the other unit. The operator's manual (ref. 3.4-2) shows six pages of frequency charts illustrating the combinations of frequencies for which two transceivers can not be used. For a typical frequency of 33.05 MHz, the PRC-25 manual lists 14 channels (out of 420) on which the relay will not operate. Measurements at Page Communications Engineers, Inc. indicate that the number of channels on which interference is observed is closer to 236.

For application as a multi-channel F_1-F_2 relay component, the PRC-25 will have to be enclosed in an external shielded enclosure, and outboard power filtering, RF filters, and hybrid networks will be required. The receivers may be isolated by resistive dividers following a preamplifier which makes up for the divider loss. It will be necessary to isolate the receiver input and transmitter output connections in the transceivers. Transmitter combining may use reactive hybrids to minimize power losses.

A high-speed commutated F_1-F_1 relay package has been demonstrated by Motorola, using a rather extensively modified PRC-25 (ref. 3.4-3). Modification for low-speed commutation would require essentially the same changes, with the addition of a multi-channel storage device.

3.4.2.3 <u>AN/PRC-77</u>

The PRC-77 (ref. 3.4-4) is a more recent version of the AN/PRC-25, with a solid-state transmitter power amplifier. The same considerations apply to its incorporation in a relay package as for the PRC-25.

3.4.2.4 <u>AN/PRC-70</u>

The PRC-70 (ref. 3.4-5) is a higher-power transceiver for HF and VHF use in SSB, AM, FM, CW modes. The frequency synthesizer provides tuning in 1 kHz increments, with continuous interpolation available. The transmit and receive frequencies are identical. No provision for relay use is indicated.

3.4.2.5 <u>AN/PRC-72</u>

The PRC-72 (ref. 3.4-6) is a modular transceiver employing plug-in subassemblies for HF, VHF, and UHF use. The VHF - FM unit tunes from 38-50 MHz, restricting its applicability to relay use. Interconnections for F_1-F_2 relay use are incorporated, presumably in a manner similar to the PRC-25.

3.4.2.6 AN/PRR-9 and AN/PRT-4

The PRR-9 and PRT-4 (refs. 3.4-7, 3.4-8, and 3.4-9) are ultra-miniature units designed for intrasquad and platoon communication. The transmitters provide two channels (separated by less than 1 MHz) while the receiver is preset to a single frequency between 47 and 57 MHz. The receiver is of particular interest as a means of providing a second receiver channel for a PRC-25 or PRC-77 used with a F_1-F_2 relay.

3.4.2.7 AM-4306

The AM-4306 (ref. 3.4-10) is an outboard solid-state power amplifier for use with the PRC-25 and presumably with the PRC-77. The 25 w. power output is available over the 30-76 MHz PRC-25 tuning range. Tuning is broadband, in two ranges, so little suppression of spurious output products from the associated transceiver is to be expected.

3.4.2.8 AN/ARC-44

The ARC-44 (ref. 3.4-7) is an aircraft VHF - FM transceiver compatible with the PRC-25 over the 30-51.9 MHz portion of its tuning range, on alternate PRC-25 channels. Provision is made for single-channel F_1-F_2 relay application. This is an older equipment in standard B status.

3.4.2.9 AN/ARC-54

The ARC-54 (ref. 3.4-11) is a replacement for the ARC-44, tuning 30-69.95 MHz in 50 kHz spacing, and is designed for compatibility with the PRC-25 and VRC-12 families. Useful range is listed as 25 miles at an altitude of 500 ft. The receiver sensitivity is apparently 7 db worse than the PRC-25, possibly as a compromise with dynamic range requirements.

3.4.2.10 AN/ARC-114

The ARC-114 (ref. 3.4-7) is a completely solid-state replacement for the ARC-54 for application in the LOH and other fixed and rotary wing aircraft. Provisions for single-channel relay operation are incorporated.

3.4.2.11 AT-430

The AT-430 (ref. 3.4-12) is an airborne version of the AN/PRC-70, with similar performance specifications.

3.4.2.12 Selection of VHF - FM Relay Equipment

On the basis of our review of the available equipment, we feel that the following equipments offer the greatest prospect of adaptability to multiple-channel relay operations:

1. AN/ARC-114, which is designed for airborne application, has sufficient power output to compensate for hybrid losses, and is physically compact.

2. AN/PRC-77, the all solid-state version of the AN/PRC-25.

3. AN/PRC-25, relatively inexpensive and available.

The other units considered have either reduced or excessive versatility, or excessive weight, bulk, or power requirements. Interface problems in adapting the PRC-25 and PRC-77 to airborne use tend to point toward the ARC-114 for the initial and interim time-frame applications. It may not be safe to assume that the ARC-114 is completely free of the spurious response and RF leakage problems which have been noted in the PRC-25, so some additional filtering and shielding may be required for F_1-F_2 multiple-channel relay operation.

The prior work in modifying the PRC-25 and PRC-77 for F_1-F_1 commutated switching may possibly reduce development time involved in producing an F_1-F_1 switched relay for the interim time frame.

3.4.3 UHF - AM Relay

3.4.3.1 General

In areas where foliage attenuation is not a factor in the ground-to-relay power budget, there may be some significant frequency allocation advantages in the use of UHF relaying for tactical communications. There is a limited number of UHF pack-set transceiver equipments, there are more vehicular and airborne transceivers, as well as one equipment specifically designed as an airborne relay, the AN/ARC-97. The following paragraphs describe the equipment summarized in Table 3-3.

UHF - AM Equipment	Status	Weight lbs.	Volume $ft.^3$	Power Input (XMT) Watts	Power Out Watts	Freq. Range MHz	Freq. Increment kHz	Rcvr. Sens. $\mu v.$	Remarks
AN/PRC-71	DEV	11 [(1)]	0.2 [(1)]	50	10 P.E.P. 3.5 avg.	230-360(R) 300-400(T)	-	5	40 MHz R-T Freq. Separation in relay modification
AN/PRC-72	DEV	12 [(2)]	0.43 [(3)]		1	240-350	3000 min spac-ing		4 Preset chans.
AN/ARC-51	STD A	31	0.7	340	20 avg.	225-400	50	2-4	18 Preset chans.
AN/ARC-116	DEV	10	0.09	36 avg.	40 P.E.P. 10 avg.	225-400	50	4	
AN/ARC-97	PROD	23	0.44	280	4	225-400	-	5	Relay [(1)]
AN/VRC-24	STD A	82			15	225-339.9	100		AN/TRC-68 is similar
AN/GRC-134	PROD	95	2.75	680	50	225-400	50	3	

NOTES: (1) Simplex relay configuration
(2) Estimated
(3) Volume including battery pack

Table 3-3. UHF - AM Equipment Summary

UHF - AM Equipment	Status	Weight lbs.	Volume $ft.^3$	Power Input (XMT) Watts	Power Out Watts	Freq. Range MHz	Freq. Increment kHz	Rcvr. Sens. µv.	Remarks
AN/PRC-66	DEV	$4^{(4)}$	65 in^3	16	2	225-400	50	3	
AN/ARC-109	DEV	25.9	0.16	300	30	225-400	50	3	

NOTES: (4) Excluding battery

Table 3-3. UHF - AM Equipment Summary (Sheet 2 of 2)

3.4.3.2 AN/PRC-66

The PRC-66 (ref. 3.4-13) is a developmental UHF - AM transceiver employing thin-film and integrated circuit techniques in the interest of size, weight and power savings. The PRC-66 uses a frequency synthesizer to select any of the 3500 channels in 50 kHz steps.

3.4.3.3 AN/PRC-71

The PRC-71 (ref. 3.4-14) is a UHF - AM transceiver under development by Sylvania. The specifications listed in Table 3-3 are based on a report of an F_1-F_2 relay adaptation of this equipment, so actual pack-set parameters may differ somewhat. In the balloon and drone-borne relay applications, the modified transceiver operated at external temperatures of -76°C and an altitude of 80,000 ft.

3.4.3.4 AN/PRC-72

The PRC-72 (ref. 3.4-6) was previously mentioned under VHF relay equipment. One module of the set provides 4 preset channels between 240 and 350 MHz, with 1 watt output power.

3.4.3.5 AN/ARC-51

The ARC-51 (ref. 3.4-15) is an AM transceiver tuning 18 pre-set channels out of the 3500 50 kHz spaced channels from 225 to 400 MHz, plus one guard channel. While this equipment is comparatively bulky and extravagant of power, its availability and aircraft qualification may make it worth consideration for interim time-frame application.

3.4.3.6 AN/ARC-116

The ARC-116 (ref. 3.4-7) is part of the equipment designed for use in the LOH, and represents a substantial improvement in weight, bulk, and power consumption over the ARC-51.

3.4.3.7 AN/ARC-97

The ARC-97 (ref. 3.4-16) appears to be the only equipment specifically designed as a single-channel F_1-F_2 relay. Frequency control is by changing crystals and transmitter tuned lines. The ARC-97 includes two receivers and two transmitters to permit unattended relaying in two directions. Whether more than one ARC-97 can be operated in a single aircraft would have to be determined, but provision of an external receiver multi-coupler, transmitter hybrid network, and diplexer should permit stacking multiple numbers of channels.

3.4.3.8 AN/VRC-24

The VRC-24 (ref. 3.4-7) is included as an example of a vehicular equipment with which a UHF - AM relay might operate. 20 preset channels, with 100 kHz spacing, are available out of the potential 1750-100 kHz spaced channels. The AN/TRC-68 is a transportable version of the same equipment, for airport control use.

3.4.3.9 AN/GRC-134

The GRC-134 (ref. 3.4-17) was initially applied to the Marine Tactical Data System, and has also been selected for use in the USAF 407L program. One synthesizer supplies both receiver and transmitter, and the RF circuits in both are servo-tuned. While nominally a fixed or mobile ground unit, the GRC-134 is readily adaptable to airborne use.

3.4.3.10 AN/ARC-109

The ARC-109 (ref. 3.4-18) is a developmental model of an aircraft UHF transceiver making extensive use of microelectronic techniques for reducing size and weight, and increasing reliability. The remote tuning provisions at a binary-coded decimal low-level interface could be of use in remote selection of relay channels in an unattended relay platform, although the power input requirements of 100 watts receive and 300 watts transmit would restrict its use to the larger unattended platforms, e.g. the QM-50D DASH drone helicopter.

3.4.3.11 Selection of UHF - AM Relay Equipment

The choice of UHF - AM relay equipment is made easier by the availability of the ARC-97. As an alternative, the modified PRC-71 used in the balloon/drone borne relay tests appears to have performed satisfactorily as a simple relay, and could presumably be adapted as a half-duplex relay as in the ARC-97. The ARC-116 could presumably be modified as described for other transceivers in either the F_1-F_2 or switched F_1-F_1 modes.

3.4.4 Multichannel UHF/SHF Relay Equipment

3.4.4.1 General

One of the functions for which the airborne platform relay appears to offer a significant advantage is that of point-to-point multichannel relaying. This is an alternative to the use of tactical tropospheric scatter or future satellite relay equipment. In comparison with the tropospheric scatter point-to-point link the ground-air-ground relay offers the following advantages:

a) Rapidly deployable.
b) Minimal in transport weight and POL requirements.
c) Capable of operation over difficult terrain.
d) Use of standard tropo scatter equipment.
e) Less exposure to jamming than synchronous satellite relay.

The relay system would be applied to temporary use, as in the transistional stages of moving a division headquarters, replacing damaged point-to-point links, augmenting channel capacity, or establishing multichannel links over difficult or enemy-held terrain where conventional relay equipment could not be installed.

At the present time, the airborne relay may offer quicker reaction time than satellite relaying, for large numbers of channels. The potentially higher power available at an airborne platform eases the requirements for ground antennas. Fixed antennas aimed generally along the great-circle point-to-point path can be sufficiently non-directive to permit the platform considerable freedom in the choice of a flight pattern.

As an objective, the ground terminals should be transportable by helicopter. The ground terminal package would include multiplex terminal equipment, power generator, and antenna system. It would be anticipated that because of the need for interfacing with telephone terminal equipment or fixed relay links, the ground terminals would be sufficiently fixed in location to permit installation of elevated antenna support structures or clearing sufficient foreground vegetation to provide a line-of-sight path to the platform.

There appears to be only one area in which the performance of the airborne relay needs to deviate from standards for point-to-point relay links. This relates to interruption of the circuit while performing handover from one platform to another.

Practical margins for fading protection may require the use of diversity, perhaps through frequency separation or ground antenna spacing.

Frequency diversity may provide a useful means of overcoming antenna pattern fluctuations on the platform.

Interfacing with other systems at the ground terminals is assumed to take place at a baseband level, most probably in baseband assignment compatibility with groups as used in the TRC-24, TRC-90, MRC-107, or MRC-85 multiplex plans, for maximum flexibility of application. No monitoring or channel dropping is envisioned at the relay platform, although a UHF order-wire channel accessible to the radio operator or pilot will be necessary for handover coordination.

The following paragraphs describe equipment suitable for multichannel relaying requirements. One such equipment, the AN/ARC-89(V) is specifically designed for multichannel air to ground relaying, and is an apparent first choice for the service considered, although the equipment is not otherwise used for point-to-point service. Table 3-4 summarizes the equipment characteristics. As previously, the table gives the weight, volume, and input power requirements for one of the two units necessary for a duplex relay package.

3.4.4.2 AN/ARC-89(V)

The ARC-89 is an operational equipment consisting of the AN/ARR-71 (ref. 3.4-19) and the AN/ART-47 (ref. 3.4-20) designed for UHF air to ground relaying of a 12 channel baseband, and has been applied to USAF airborne command post applications (ref. 3.4-21). Two such equipments would provide full-duplex relay operations at the airborne platform, while similar equipments at the ground would permit use of the system's 225 to 400 MHz tuning range. Fixed frequency FM tropospheric scatter terminal equipment may be compatible in the upper 50 MHz, such as the low frequency version of the AN/FRC-39(V). The GRC-103 should be compatible for 4 channel relaying, using the AN/TCC-3 multiplex, and possibly for 12 channel FDM with the AN/TCC-7.

3.4.4.3 AN/GRC-103

The GRC-103 (ref. 3.3-7) is a UHF line-of-sight relay equipment capable of 12 channel time division multiplex transmission. This equipment is the basis of the AN/TRC-107, a jeep-mounted 12 channel terminal. The GRC-103 is to replace the TRC-24 for forward area communications, although the units are not entirely mutually compatible in RF coverage or modulation capability. The weight and power requirements of the GRC-103 are feasible for application in a helicopter platform. Two GRC-103 equipments plus external diplexing filters would be required for airborne relay application.

Table 3-4. UHF - SHF Multichannel Equipment Summary

Multichannel Equipment	Status	Weight lbs	Volume ft.^{3}	Power Input Watts	Power Out Watts	Freq. Range MHz	Number of Voice Channels (1)	Rcvr. Noise Figure, db	Remarks
AN/ARC-89(V)	PROD	158	2.65	4000	1,000	225-400	12	3 (2)	AN/ART-47 plus AN/ARR-71
AN/GRC-103	PROD	130	2	250	15	220-405 395-705 695-1000	24		In production with 220-405 MHz plug-in head
AN/TRC-24	STD A			1100	75	50-100 100-225 225-400 400-600	12		
AN/GRC-66	DEV	350		800	5	1700-2400	96	—	1700-2400 MHz head not avail.
AN/GRC-66 (ETA)	PROD	400		850		4400-5000 ETA			
AN/TRC-29	STD A	3700		1500	10	1700-2400	48		
AN/GRC-50	STD A	325		1100	20 10	600-1000 1350-1850	24		
MA-2T	PROD	62	1	285	15	2200-2300		6	Microwave Associates, Inc.
FMT/FMR 1900-ATR	PROD	70	1.5		1	700-1000 1400-1900 1900-2300 4400-5000 6800-7200		11	RHG Electronics Laboratory, Inc.

NOTES: (1) Nominal, with typical multiplex equipment.
(2) Sensitivity, μv.

Table 3-4. UHF - SHF Multichannel Equipment Summary (Continued)

Multichannel Equipment	Status	Weight lbs.	Volume ft.^{3}	Power Input Watts	Power Out Watts	Freq. Range MHz	Number of Voice Channels	Rcvr. Noise Figure, db	Remarks
AN/GRC-144	DEV	375	13.5	420	250 mw	4400-5000	12/24/48/96 PCM 120300 FDM	4.5	LOS (3)
AN/TRC-112	STD A		26.5	5,420	1 kw	4400-5000	12/24/48/96 PCM 120300 FDM	4.5	TROPO version(3)

NOTE (3) Figures do not include Mux Equipment.

3.4.4.4 AN/TRC-24

The TRC-24 (ref. 3.4-7) is the basis of a number of UHF point-to-point relay and terminal sets. Various RF ranges are covered by different versions of the set, from 50 to 600 MHz. 12 channel FDM capability is available with the AN/TCC-7 multiplex. The weight and power requirements of the TRC-24 do not recommend it for airborne use, but it may be a potential ground terminal for ARC-89, GRC-103, or other relay units in the airborne platform.

3.4.4.5 AN/GRC-66

The GRC-66 (ref. 3.4-7) is the basis of a number of SHF point-to-point relay and terminal sets, with 96 channel PCM capability. The low output power in comparison with the weight and power consumption make this a relatively undesirable equipment for either ground or airborne use with low-gain antennas.

3.4.4.6 AN/TRC-29

The TRC-29 (ref. 3.4-7) is used as the basis of the TRC-38 terminal set and TRC-39 repeater set. Again, this equipment is not suitable for airborne use by reason of its weight, but could possibly function as a terminal of a relay augmented multichannel link. The TRC-29 is compatible with the 1700 to 2400 MHz version of the GRC-66 and uses PPM multiplex equipment.

3.4.4.7 AN/GRC-50

The GRC-50 (ref. 3.4-7) is a relatively lightweight forward area relay set, compatible with the GRC-66 and TRC-29 over a portion of the tuning ranges, from 1750 to 1850 MHz. The GRC-50 is capable of 24 channel PCM with the AN/TCC-54 multiplex. The GRC-50 could possibly find application as a SHF airborne relay, but may not be compatible with aircraft shock, vibration, and altitude requirements.

3.4.4.8 Tropo Scatter Equipment

A number of contemporary transportable tropospheric scatter terminals provide a convenient low-power interface between the exciter and the power amplifier, typically at the 1 to 10 watt level. It may be feasible to use this equipment without the power amplifier in temporary airborne platform relay applications. There is a decided logistic advantage in limiting the number of different equipment types to be deployed in an area, and an advantage in not requiring different or additional training for terminal operating personnel. Direct compatibility at baseband or channel interfaces with identical tandem links is a further benefit.

An example of a contemporary tropospheric scatter system which would be compatible with this concept is the AN/MRC-107, operating in the 5 gHz band. Similar receivers and exciters are available in the 350 to 450, 755 to 985, 1700 to 2400, 2400 to 2700, 4400 to 5000, and 7500 to 8500 MHz bands (ref. 3.4-22, 23).

3.4.4.9 TV Relay Equipment

A potentially useful source of lightweight broadband relay equipment is television relay equipment, both commercial and military. While both systems listed provide bandwidths in excess of the requirement (12 MHz baseband in comparison with 120 kHz for 24 channels) the subsidiary benefits of weight, availability, and aircraft compatibility should be considered.

Microwave Associates Model MA-2T, (ref. 3.4-24) is solid state except for a travelling wave tube power amplifier, providing 15 watts output in the 2200 to 2300 MHz range. RHG Electronics Laboratories, Inc. model FMT/FMR 1900 ATR (ref. 3.4-25) provides 1 watt output from the basic 1900-2300 MHz solid-state transmitter, with external power amplifiers available. The RHG units are mounted in ATR cases compatible with standard shock mount trays. RHG indicates that 100 w. power output is available as an option, and that versions of the equipment from 0.7 to 7.2 GHZ are available

3.4.4.10 Selection of UHF/SHF Multichannel Equipment

The AN/ARC-89 (V) equipment, designed specifically for ground-air-ground relay application, appears to be the most logical choice for initial or interim time frame application. The RHG television relay equipment, again designed for airborne application, is the next best choice, although the lower power and higher operating frequency restrict its range. The use of higher-gain antennas at the ground would offset these restrictions, and the development of directional antennas for the platform would help the power budget and ease interference problems.

3.4.5 Platform - Relay Interfaces

3.4.5.1 General

A number of interface areas between the relay package and the high-altitude platform must be considered in the design of a workable system. The following paragraphs discuss the physical, environmental, and electrical interfaces which need to be considered.

3.4.5.2 Physical Characteristics

3.4.5.2.1 Weight

The total weight of a relay package providing relay service for 6 VHF FM channels using 12 AN/PRC-77 or AN/PRC-25 transceivers* would be approximately 320 lbs., of which half is an allowance for shock mounting, shield and environmental housing, interconnecting wiring and power RF filters. A 12 channel package would perhaps best be two of the 6 channel packages, to facilitate loading into aircraft. The alternative AN/ARC-114-based 6 channel relay package would weigh less than 144 lbs.

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* It is assumed that the relay must be compatible with single-frequency tactical radio sets for the initial and interim time frames, as shown in Figure 3.2-3(a).

A 6-channel UHF relay package employing the AN/ARC-97 would total perhaps 350 lbs., or 195 lbs. with the AN/ARC-116. In each case, 75 lbs. was allowed for mounting, enclosure, filtering, etc.

If attended operation of the 6 or 12 channel VHF or UHF relay packages is desired, a small switchboard and an order wire transceiver (preferably AN/ARC-114 or AN/ARC-116) would also be required, possibly totalling an additional 50 lbs.

The 12 channel point-to-point duplex relay package employing the AN/ARC-89 will weigh 320 lbs. plus an estimated 100 lbs. for diplexing filters, and interconnecting cables. Since the individual units of this assembly are designed for airborne application and no on-board channel demodulation is planned, no additional shielding should be required, and the ARR-71 receivers and ART-47 transmitters may be mounted in a lightweight equipment rack.

3.4.5.2.2 Volume

The volume required for some of the more promising 6 and 12 channel relay packages is as follows:

1. The six channel package made up of 12 AN/PRC-25 or PRC-77 transceivers requires about 3.4 cubic feet of volume. Another 100% should be added for housings, shock mountings, etc., making total volume of about 6.8 cubic feet.

2. The AN/ARC-114 (or ARC-116) 6 channel package would require 0.9 cubic feet of volume for the transceivers. An additional 100% of volume should be added for housings, shock mountings, etc., making a total of 1.8 cubic feet.

3. The AN/ARC-97 6 channel package (6 ARC-97's) requires 2.6 cubic feet for the transceivers, and an additional volume for shock mounting, diplexing filters, etc., bringing the total to approximately 5 cubic feet.

4. The AN/ARC-89 components for a duplex relay facility would total 5.3 cubic feet, plus an allowance for diplexing filters and shock mounting to bring the total to 10 cubic feet.

Various other factors in relay package design, such as environmental protection for the package suitable for outdoor storage prior to temporary installation in aircraft, requirements for cooling, etc. may enter into the weight and volume consideration.

3.4.5.2.3 Modularity

In scaling relay physical parameters to a particular channel capacity, it is evident that the designs employing multiple transceivers will have common equipments which do not change in weight and dimensions with each increment of channel capacity. Common equipment in the relay may include diplexing filters, receiving preamplifiers, power splitters, transmitter summing networks, power regulators and supervisory equipment. Of these, the diplexing filters are the only significant items which will not increase strictly in proportion to channel capacity, since the filter requirements are substantially the same for any number of channels.

The use of a number of separate modules for the relay may improve the efficiency of use of available space in various platforms, at the expense of increasing the number of interconnecting cables and the total weight. A building-block approach to the channel capacity requirements suggests that packages of 6 transceivers might be a useful division.

3.4.5.2.4 Spares

The use of 10% spares should be adequate for equipment, such as the AN/PRC-25, with a 2000 hour mean time between failures, (MTBF). For a system made up of 12 transceiver equipments and with missions averaging 10 hours in duration, a failure should average only once per 17 missions. The more modern all-solid state equipment have a much longer MTBF, thus the AN/PRC-77, which has a MTBF of 25,000 hours, should require no airborne spares at all. A 6 channel system, using 12 AN/PRC-77 transceivers should have a failure occurring only once per 208 missions of 10 hours duration.

If the relay is unsupervised, failure of a particular relay channel may result in relay service not being available to a particular organizational unit or detachment. If a relay operator is responsible for assigning channels, he may ignore an inoperative channel and route traffic through the remaining channels, at some increase in traffic density and waiting time.

3.4.5.3 Environmental Factors

3.4.5.3.1 Vibration and Shock

The vibration and shock specifications for the relay package should not have to take exception to appropriate sections of MIL-E-5400. A number of the recommended basic units for the package already meet such specifications, and should not require further proof of compliance, provided that their mountings or enclosures are not appreciably changed in adapting them to relay service.

The use of pack-set equipment as a relay basis, e.g. the PRC-77, may require special testing to verify compliance with appropriate specifications. For application to the initial and interim time frame requirements, however, it is anticipated that external shock and vibration protection will be used, rather than redesigning internal transceiver components.

3.4.5.3.2 Temperature and Altitude

Again, there should be no exception to the MIL-E-5400 specifications for avionics equipment for the overall equipment package. If equipment is to be used under extraordinary conditions, e.g. balloon-borne relay operation, the use of external pressurized containers may permit application of otherwise unsuitable low-altitude equipment. Cooling must be given careful consideration in planning external shielding or environmental protection.

3.4.5.4 Platform Antenna

3.4.5.4.1 Polarization and Orientation

Antennas for use on the airborne platform should ideally be circularly polarized, to accommodate any ground antenna polarization, and to make the system gain independent of platform orientation. Similarly, an ideal antenna would have an isotropic radiation pattern with respect to gain variation, but sharp cutoff at the horizon to minimize interference generation and susceptibility. In point of fact, both pattern and polarization are severely constrained by the platform structure.

While the pack-set antenna is nominally vertical, the actual orientation may be at any angle, and, together with re-radiation by foliage will tend to give an elliptically polarized signal or response. The gain patterns of the ground and platform antennas are relatively broad, and there may be a considerable angle of error before the system gain is seriously affected.

3.4.5.5.2 Antenna Location and Mounting

Several criteria for antenna locations should be considered:

1. The antenna should be vertically or elliptically polarized.

2. The antenna should be as well isolated as is practical from propellor or rotor blades, to avoid modulation of the antenna pattern.

3. The antenna should not degrade aircraft performance, nor impede landing and takeoff.

4. The antenna should require a minimum of airframe modification.

5. The antenna should not disclose the special mission of the aircraft.

6. The antenna pattern should be as insensitive as possible to aircraft orientations during normal maneuvers in pitch roll, or yaw.

While the weighting of these criteria is subject to some question, there are several useful observations which may be made concerning potential antennas and locations.

For the UH-1D helicopter, a whip antenna location directly beneath the fusilage would provide some isolation from rotor modulation, a pattern more or less omnidirectional in azimuth, and some gain reduction at the horizon. It should be possible to obtain or devise an antenna mount which would either permit bending in any direction or permit retraction of the antenna during landing and takeoff. Such an antenna could be clamped to the landing skid struts to facilitate installation and removal. A small diameter whip would be relatively difficult to resolve from the ground.

The present VHF whip which extends from the UH-1D tail boom undoubtedly shows a substantial amount of rotor modulation, and presumably has a pattern null in the forward direction, but otherwise meets the criteria of polarization, platform compatibility, and concealment.

Reduction of gain margins required for multichannel systems may be accomplished by frequency diversity using two or more antennas on the aircraft, as a means of filling-in nulls in each patterr

3.4.5.5 Power Supply

The use of platform power, when available, is the most efficient means of supplying primary power to the relay equipment. Even if the quality of the power supplied by the platform is poor, voltage regulators, filters, etc., are readily available. A satisfactory regulator for 500 watts, which should provide ample power for a 6 to 12 channel relay system, would weigh less than 10 pounds and require less than 0.1 cubic foot of volume. It should be noted that semiconductor devices are particularly intolerant of high voltage transients, and the application of pack-set equipment such as the AN/PRC-77, designed for battery operation requires careful attention to transient suppression.

Any suitable secondary or auxiliary power supply would require substantially more weight and volume. For example, a secondary battery supply capable of supplying 10 watt-hours per pound would require 50 pounds to supply 500-watt hours, although lithium-copper fluoride primary batteries having a capacity of 80 watt-hours per pound are in the development process.

Most airborne vehicles have some primary power available, with no additional weight required. If added primary power is required, the added weight required for a larger generator may be at a rate as little as 10 pounds per horsepower, or 74.6 watts per pound. This value is based on present generators designs and should be improved substantially in the future. Fuel cells of adequate capacity and reliability may be able to replace electromechanical generators for auxiliary power functions of this sort in a few years.

3.4.5.6 Electromagnetic Interference Compatibility (EMI)

The conceptual design of the multi-transceiver relay package is predicated on the assumption that the interference between the relay and platform avionics equipment and the interference between adjacent transceiver equipments may be held to satisfactory levels. Further investigation of the interference generation and susceptibility of the AN/PRC-77, PRC-25, AN/ARC-114 and other transceivers is needed before specific relay package is designed. The results of such an investigation may indicate necessary filtering, shielding, power supply decoupling, tuning range limitations, and in general, the suitability of the transceiver equipment for multiple relay service.

The relative desirability of equipment specifically designed to meet RF compatibility specifications is evident. This favors particularly the equipment designed especially for relay service, the AN/ARC-97 and the AN/ARC-89V, and to a lesser degree (since the other equipments require modification) the other aircraft radio equipments. A longer range relay development program,of course, would require attention to EMI problems during design and qualification.

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3.5 POTENTIAL FOR RELAY DEVELOPMENT

3.5.1 Optimized Relay System Design

3.5.1.1 Objectives

It is evident that the use of existing equipment for the relay application is intended as a stop-gap measure to shorten the cycle of development, trial, and operational deployment. For the longer range objective, we are more at liberty to apply techniques and components which are not now in military usage, inventory, or development. Among the long range objectives for relay systems are:

1. Simplification of relay hardware.
2. Development of relay packages compatible with a variety of platforms.
3. Development of tactical radio equipment designed for optimization of both relayed and conventional operational modes.
4. Compatibility of relay with digital modulation modes.
5. Reduction of interference generation and susceptibility.

One is constrained, even in planning for the long-range objectives, to maintain a degree of continuity in equipment development, since phasing-out of older equipment is a slow process. This is especially true in counterinsurgency warfare, where indigenous military and paramilitary forces may be equipped with earlier U. S. radio equipment.

The following paragraphs describe some of the features of optimized relay designs, primarily in regard to relays designed for FM-network augmentation, but also in reference to possible UHF-AM network relaying and the multichannel trunk relay problems.

3.5.1.2 Relay Design

All of the relay packages recommended for initial and interim time frame application consist of assemblies of single channel equipment. While this is a necessary expedient, there may be substantial room for improvement of relay complexity, size, and reliability through an overall simplification of the relay package. Can the more extensive use of equipment common to two or more channels bring about any net economies or performance improvement?

1. The use of broadband relays covering several channels

simultaneously increases the susceptibility to unintentional interference or to deliberate jamming.

2. All subscribers within the service range of the relay will have to avoid the relay's segment of the spectrum if they do not need relay service.
3. If a broadband relay does not provide separate AGC for each up-link channel, then some sort of automatic power control must be incorporated in the pack sets themselves so that all signals to be relayed arrive at the platform at approximately the same level. Frequency-translated down-link signals are not a good basis for level comparison, since signal levels observed at two frequencies from a jungle-immersed antenna may be substantially uncorrelated.
4. Maintaining the intermodulation products from the broadband relay at a tolerable level requires design of the relay transmitter for high peak power capability, with consequent high power input requirements and transmitter cooling requirements. On the other hand, hybrid combining of separate transmitters is not very efficient either.
5. Failure of a broadband relay may jeopardize several military units simultaneously. There may therefore be a need for standby equipment with manual or automatic switchover provisions.
6. Useful savings should be possible in the equipment common to the channel frequency synthesizers.

The conclusion of the above considerations seems to be that a broadband relay package needs to provide single-channel preselector filtering and separate AGC for each channel. The principal difference from a multi-transceiver relay package would be the use of broadband power amplifier common to all of the receiver channels. The peak power requirement should not be a problem for the larger platforms.

As for the long-term implications of common-frequency (switching) and frequency translating relay techniques, the question of compatibility with digital modulation formats would appear to be a critical factor. The elevated platform increases the risk of message interception and spoofing, so the use of a relay mode compatible with digital modulation appears to be indicated. The common-frequency non-switching relay should be PCM compatible, but leaves some question as to its adaptability to relaying more than one channel at the same platform.

Passive reflectors appear to offer too little path gain to be useful for pack-set relaying, but may find application in point-to-point multichannel application where the reflector correlation bandwidth permits.

The multichannel HARR application would benefit from the use of a simple field-transportable tracking antenna of modest size capable of following high-altitude balloons or other reflecting devices.

The multichannel relay application would also benefit from the development of a platform mounted antenna capable of providing useful directivity toward the ground terminals or other airborne terminals, yet keeping gain fluctuations due to platform motion to a minimum. Such antennas would not need to track the received signals from the ground or other aircraft, but could be directed by the platform's navigational facilities, or through a link between navigational facilities at two such platforms.

3.5.1.3 Ground Terminal Design

It was noted in Section 3.2 of this report that the pack-set radio design constrains the relay network operation in several ways. The most awkward problem with contemporary pack-set radios is the use of single-frequency operation, with one local oscillator or synthesizer controlling both receiver and transmitter. Provision for independent receive and transmit frequency selection would be the ideal solution (from the relay designer's point of view) but a fixed switchable frequency offset would perhaps be more reasonably incorporated in the pack-set.

Use of contemporary RADA vacant channel search procedures in a tactical network context appears to be dangerous, in that a captured pack-set could be used to elicit automatic responses for direction finding and fire control.

There would appear to be considerable room for improvement in pack-set antennas for jungle operation. Further examination of the potential of frequency diversity and the use of magnetic loops instead of, or in addition to whip antennas may lead to useful results. Recent work on the "energy density" antenna (ref. 3.5-1, 2) suggests that a substantial improvement in fading may be achieved through the use of this technique.

3.5.2 Satellite Relay

3.5.2.1 Introduction

The use of earth satellites is rapidly augmenting and replacing military long-haul communications circuits using hf radio, ionospheric scatter, undersea cable, and tropospheric scatter. The potential of satellite communications for use in the present context of tactical communications remains to be exploited. The following paragraphs consider briefly the use of satellite relaying for tactical pack-set application and for UHF/SHF multichannel communications.

3.5.2.2 Satellite Location

The availability of satellites in orbits from a few hundred miles to synchronous orbits leads to an initial question of the proper satellite orbit location for tactical support. If a given theater is to be supported by satellite relay, the frequency assignment problem is quite complicated. A synchronous satellite could act as a relay for a selected group of channels which would remain fixed, or could change channel assignments remotely in accordance with the SOI schedule. Sub-synchronous satellites, however, would require separate frequency assignments or else would have to be switched on-and-off by a ground control station which would assure that only one satellite would be assigned to a given frequency range at a time, while in view of the operational area. The same frequency range could be used in areas which did not have the satellite in view simultaneously. With this provision, satellites at any altitude could be used subject to the constraints of power and ground station complexity.

3.5.2.3 VHF/UHF Pack-set Relay

In order to use a satellite relay for pack-set range augmentation, the satellite must have sufficient receiver sensitivity and power output that directional antennas are not required on the ground. The field of view of a satellite is large enough that an exclusive channel assignment will be required for the up and down-link frequencies. Since the military services share the VHF (30-70 MHz) spectrum with a variety of other services, it is unlikely that such assignments can be obtained. The situation is somewhat better at VHF (225-400 MHZ) where military traffic predominates, and agreements could be made between friendly governments regarding assignment of portions of the band to relay functions.

It may be useful to consider the necessary parameters of synchronous satellites and ground terminals for this service. If we take the up link as limiting performance, and base antenna performance on that achieved in the NASA ATS satellits, the power budgets of Table 3-5 may be postulated. Circular polarization of the satellite antenna is assumed, and satellite receiver bandwidths are taken as 36 KHz for VHF-FM and 4 KHz for UHF-AM.

Frequency, MHz	30	76	225	400
Transceiver Power Output, dbw	0	0	0	0
Transceiver Antenna Gain, db	0	0	0	0
Free-Space Loss, db	-153	-161	-170.5	-175.5
Satellite Antenna Gain, db	10.5	10.5	10.5	10.5
Received Carrier at Satellite, dbw	-142.5	-150.5	-160	-165
Satellite Receiver Bandwidth, db/1 Hz	45.5	45.5	36	36
Satellite Receiver Noise Temperature, db/1° K	30	30	30	30
Boltzman's Constant, dbw/Hz/° K	-228.6	-228.6	-228.6	-228.6
Receiver Noise Level, dbw	-153.1	-153.1	-162.6	-162.6
Carrier to Noise Ratio at Satellite, db	10.6	2.6	2.6	2.4

Table 3-5. Up-Link Power Budget

The resulting carrier to noise ratios indicate that a considerable additional up-link system gain is needed. The vertical whip antenna associated with the pack-set has a somewhat less than ideal pattern and orientation, and so loss has been assumed for possible jungle foliage.

In view of the VHF interference problems, it seems safe to say that satellite relaying is not feasible for conventional pack-set equipments. At UHF, it may be possible to increase satellite antenna gain, ground antenna gain, and ground transmitter power enough to provide useful service for pack-sets with line-of-sight clearance to the satellite.

3.5.2.4 UHF/SHF Multichannel Relay

The use of satellite relaying is much more attractive at higher frequencies where more nearly exclusive channel assignments, wider bandwidth, and higher antenna gain are available. The size of a satellite communications terminal for 12 to 24 channel capacity can be comparable to that of a transportable tropospheric scatter system.

Since a given operational area, e.g. Viet-Nam, might require several multichannel links of this sort for temporary use (assuming that permant links are maintained by tropospheric scatter or submarine cable) it will be necessary to equip the satellite for sharing one or more transponder channels. This may be accomplished through several possible multiple access techniques.

The central question seems to be whether there is a justification for equipping "high altitude" platforms for multichannel relay when satellite relaying is becoming practical for transportable terminals. The satellite terminal will undoubtedly be a specialized equipment with specially trained operators. It would be possible to implement high-quality HARR relay links using groundterminals of the sort employed for conventional LOS or tropo links, with the possible exception of using lower-gain antennas than is usual.

Activation of a HARR link could be at the local commander's option, while use of satellite channels may require extensive coordination. On the other hand, the satellite interference generation and susceptibility are more readily controlled through the responsible agency than would be the case for somewhat independent HARR platform usage.

The delay implicit in replacing defective satellites is perhaps a justification for the use of a HARR relay for temporary backup of satellites used for moderately short paths, although with enough satellites in orbit, there will usually be alternates available.

In a situation involving jamming, there may be an advantage in minimizing the coverage area by means of a relay platform at the minimum altitude for system operation and platform safety.

In summary, it appears that even with extensive use of satellites for tactical trunk relaying, there may be a need for the HARR type of relay service as a temporary means of establishing or maintaining a multichannel link.

3.5.3 Passive and Semi-Active Reflectors

3.5.3.1 Introduction

The use of a passive reflector as a relay mechanism is attractive with respect to reliability, power requirements, rapidity of launching, and other respects, in exchange for which one must accept a low relay gain, raising ground power and antenna gain requirements. The path loss involved in a passive relay link is given by the basic radar equation (3.5.-3),

$$L_p = \frac{P_t}{P_r}\left[\frac{4\pi R_1^2}{g_t}\right]\frac{1}{\sigma}\left[\frac{4\pi R_2^2}{A_r}\right]$$

where

P_t	is transmitted power
P_r	is received power
R_1	is the distance from transmitter to reflector
R_2	is the distance from reflector to receiver
g_t	is the transmitting antenna gain referred to an isotropic antenna
σ	is the effective reradiating area of the reflector
A_r	is the effective area of receiving antenna $= \dfrac{\lambda^2 g_r}{4\pi}$
g_r	is the receiving antenna gain referred to an isotropic antenna, and
λ	is the wavelength.

The low gain or low effective reradiating area of a passive reflector makes it much more adaptable to a microwave point-to-point communications application. A microwave system normally uses high gain antennas at both ground terminals which are mounted above the surrounding foliage, or with the foliage cleared away in the path direction.

This discussion of the various types of passive reflectors should start most logically, as in Corriher and Pyron (ref. 3.5-4), with artificial electron clouds (ref. 3.5-5). This type is followed by a discussion of chaff (3.5-6, 7) then orbiting dipoles, such as those of project "West Ford" (ref. 3.5-8). The next types of reflectors, in order of increasing gain, are reflective balloons (ref. 3.5-9), retrodirective devices, such as corner reflectors (ref. 3.5-10) and Luneberg lenses (ref. 3.5-11), grated arrays of artificial scatters (ref. 3.5-12), and also passive Van Atta retrodirective arrays (refs. 3.5-13, 14).

A related group of reflectors to be considered is the semi-active relay. This system is a compromise between the purely passive type of reflector and the active type of relay, that uses an on-board power supply. The semi-active system uses a Van Atta retrodirective antenna array, which may be modulated by signals received from another direction by a second retrodirective antenna array. The power requirements of the modulator may be low enough to permit supplying power from the ground.

A similar type that requires somewhat more power than this semi-active relay is the "Antennafier" (ref. 3.5-1). It uses device as a broadband amplifier, directly at the antenna, to provide gain.

3.5.3.2 Artificial Electron Clouds

A series of tests were made, ending in 1960, of the performance of cesium vapor clouds as reflectors of radio waves. These artificial electron clouds were released from rockets at altitudes of about 100 km. The reflectivity at various frequencies, the time duration of the reflectivity and other characteristics were measured.

Gallagher and Barnes (ref. 3.5-5) found that the backscatter from the ionized cloud lasted substantially longer for daytime releases. The backscatter duration was fairly constant for frequencies up to 26 MHz, dropping off rapidly to a negligible duration between 100 and 300 MHz. Radar cross-section was found to peak at 10 km^2 at 20 MHz and to drop to 1 km^2 in the 40-50 MHz range. It is indicated that during the daytime, gas releases at altitudes above 115 km would be optimum yielding signal durations of 60 min. At night, altitudes below 95 km are necessary for maximum signal duration.

The monostatic radar cross-section values cannot be used directly to calculate path loss for ground-electron cloud-ground path. Corrections to give the bistatic cross-section are indicatedin the referenced paper. An approximate value could be obtained by multiplying the backscatter cross-section by the cosine of the angle between the receiving and the transmitting paths at the reflecting surface.

Fading rates after the burst growth period are comparable to those observed for long-enduring meteors and for the normal-mode ionospheric propagation and are considerably less than for auroral fading

Since 1960, numerous field experiments have been conducted using artificially ionized clouds to enhance radio propagation. Payloads of from 7 to 10 pounds released at 100 km produced very satisfactory results during these tests. The test evaluations indicate that artificial electron clouds can support VHF radio propagation up to at least 50 MHz over all ranges out to 1100-1400 miles and for durations to 60 minutes or more. Additional references for artificial electron cloud tests made after 1960 are shown in 3.5-46, 3.5-47, and 3.5-48.

3.5.3.3 Chaff

Chaff has been used extensively as a countermeasure against both tracking and search radars. There has been considerable recent interest in chaff for communications over non line-of-sight paths at UHF. Chaff may be dispensed by aircraft at altitudes from 10,000 feet to 30,000 or it may be dispensed by rockets at altitudes up to several hundred thousand feet. The time duration of the chaff clouds depends on the fall rate which is proportional to altitude and on the dispersion of the cloud by air currents. The fall rate is typically from 100 to 200 feet per minute at altitudes from 10,000 feet to 5,000 feet. Horizontal and vertical cloud dimensions of 2,000 to 3,000 yards have been measured in recent tests and appear characteristic, with drift rates corresponding to the horizontal component of wind velocity.

The median bistatic cross-section determined in these recent tests (ref. 3.5-6) measured 2,000 to 4,000 square meters at 1498 MHz for a 10 pound chaff unit containing 3.75×10^6 dipoles.

Chaff communications signals show rapid fluctuation in signal level at a rate of 0 to 15 Hz similar to scatter propagation. The chaff shows a non-random orientation, with the signal strength about 2.5 db greater for receiver antenna polarization at 90 degrees to the ground and to the transmitting antenna.

The distribution of signal fluctuations was computed and showed good agreement with an exponential probability distribution.

The transmission loss for chaff communications was compared with tropospheric scatter communications at a frequency of 1500 MHz. At distances of 50 miles the transmission loss for both tropospheric and chaff scatter are about equal. At a distance of 80 miles chaff communication has a 10 db advantage which increases to 20 db at 200 miles. For this distance of 200 miles, the chaff needs to be dispensed at an altitude of only 26,000 feet to provide a transmission time of 30 minutes.

A recent publication on Chaff Communications in the 4-5 GHz frequency range is shown in Reference 3.5-45.

3.5.3.4 Orbiting Dipoles

The "West Ford" experimental program to determine the properties of an orbiting dipole belt as a communications medium had two major goals. The first of these was the measurement of the propagation characteristics of this dipole belt in sufficient detail to permit the design of possible future communictions systems well matched to it. The second goal was the achievement of digital data transmission at high rates consistant with the density of dipoles in orbit. Both of these goals were substantially achieved, with digital data rates of 20,000 bits/sec. PCM voice was transmitted during the first week.

The dipole design chosen for this successful dipole belt yeilded an average orbital resonance scattering cross-section at 8,000 MHz of the order of 2,500 square meters per kilogram of mass using dipoles of copper of about 2×10^{-3} centimeters diameter and a mass of about 40 micrograms (refs. 3.5-16, 17). A total weight of about 20 kilograms of dipoles was released into orbit. Because these dipoles were distributed throughout the common volume of the two antenna beams, and because of the differential motion of the dipoles through that common volume, the received radio signals showed rapid fading, due to spreading of the Doppler frequency shift of the order of 1,000 Hz and showed a multipath time delay smear of the order of 100 microseconds (refs. 3.5-8, 16).

The backscattering cross-section of the West Ford dipole belt has been determined to be about .03 square meters (ref. 3.5-18). This was sufficient to obtain a 0 db S/N ratio with a received bandwidth of 3 KHz (ref. 3.5-8). This performance, unfortunately, was obtained only by the use of extremely high performance ground equipment (ref. 3.5-19). The West Ford Millstone Hill system operated with a transmitted power of 20 kw peak, the antenna (60 feet in diameter) had a gain of 59 db at 7,750 MHz, the antenna beamwidth was 0.15 degrees, and the receiver system temperature was 120°K. The system at Camp Parks operated with a transmitted power of 100 kw peak. the antenna (also 60 feet in diameter), had a gain of 59.75 db, with a beamwidth of 0.14°, and the receive system temperature was 60°K. When the complete system was operated in a bistatic mode, the Camp Parks transmitted power was reduced to 40KW. In both cases the receiver system temperature was obtained with the antenna pointed at the zenith.

Thus, low noise receivers, high power transmitters, and high gain antennas at both ground terminals are necessary to compensate for the very high path loss (about -210 db) of this communications system. Further limitations on the system performance are caused by the substantial Doppler shift and the multipath spread requiring the use of specially designed equipment.

3.5.3.5 Spherical Balloons

Spherical balloons may be used as passive reflectors within the atmosphere, as either tethered balloons or free-floating balloons, and can serve as their own platform. Most recent references to reflective balloons discuss their use as satellites.

For a spherical reflector whose diameter is large compared with a wavelength, the effective reradiating angle is independent of the angle between the incident and scattered path and the bistatic cross-section is given by:

$$\sigma = \pi D_s^2 / 4$$

where D_s is the reflector diameter.

Attitude stabilization is possible for a free floating balloon within the atmosphere under the action of gravity and, of course, also for a tethered balloon. The design of the balloon may then be modified to increase the effective reradiating area by increasing the radius of curvature of the bottom half of the balloon and stabilizing the balloon about the vertical axis. The radius of curvature and the useful increase in the effective reradiating area of the reflector, σ, may be increased in proportion to the degree of stabilization obtainable. The reflector diameter, D_s, should then be replaced by R_n, where R_n is the radius of curvature of the underside of the balloon. The resulting cross-section is:

$$\sigma = \pi R_n^2 / 4$$

Several methods may be used to reduce the weight of the balloon without reducing the reflective properties. The reflective coating may be made extremely thin (of the order of 1000 Angstroms) and does not need to cover the entire balloon surface, but may be made of a grid of thin ribbons, spaced a fraction of a wavelength apart.

The gain of such a passive reflector is much less than that of an active relay or satellite, but in some cases it may be substantially better than the gain of tropospheric scatter circuit. The bandwidth of a passive balloon reflector is extremely wide, since the dimensions of the balloon introduce a small path delay spread. Calculations based on power per channel mile in Ryerson (ref. 3.5-20) show that much less power is required for the ground transmitters for a 100 foot diameter passive spherical satellite in a 1000 mile orbit with a traffic capacity of one million channels (50 percent of the 8 GHz spectral space, with 4 KHz channels) than for a tropospheric scatter system of 15 links of 400 miles per link. Since there are no active components in orbit, the reliability is also much improved. There is a limitation on transmitting time, however, since the satellite is visible to both ground stations for only a fraction of the satellite's revolution. The necessity for actively tracking and acquiring the satellite on each revolution will increase the cost of the ground antennas and the associated equipment and will also reduce the reliability of the ground stations by increasing the complexity of the equipment.

3.5.3.6 Corner Reflectors

The bistatic cross-section of a corner reflector may be visualized as the product of the gain of a corner reflector antenna in the direction of interest. A downward-facing corner reflector array would therefore have a re-radiation pattern with its main lobe downward, and low gain at the horizon, as would be desired for interference and jamming considerations. Ryerson (ref. 3.5-20) indicates that the effective cross-section is not much better than that of a more easily launched balloon.

3.5.3.7 Luneberg Lenses

A Luneberglens (ref. 3.5-11) is a lens having a radial variation in the index of refraction. This lens has the property of collecting the energy which falls upon the surface of one hemisphere, refracting it through the sphere, and bringing it to a focus at the center of the surface of the opposite hemisphere. If the energy is reflected at this focal point, it will be reradiated in the direction from which it originated. As the direction of the incident radiation is changed, the focal point will shift its position accordingly. Hence, if a portion of the opposite hemisphere is covered by a reflecting metallic cap, the target will respond over a large range of angles of incidence.

A variation of the Luneberg lens called the Eaton-Lippmann lens (ref. 3.5-11) can be designed so that the signal is received on a narrow beam and transmitted without amplification on several other beams covering a wide sector. This lens requires no attitude control as do the other types of lens, using as bistatic reflectors, but it has a fixed angle between the two beams. Scanning over 360° can also be accomplished with the Luneberg lens by the use of multiple feeds spaced around the surface of the sphere (ref. 3.5.11). An analog of the Luneberg lens has been built which works by reflection only and avoids the weight, cost, and complexity of the progressively graded refracting medium of the Luneberg lens (ref. 3.5-23).

This type of reflector is usually capable of operation only for the monostatic or retrodirective mode, it has a relatively low gain, and is quite heavy, compared with types which only reflect. Even for the bistatic case, the angle between the two beams is fixed, which limits the application, and the gain is reduced.

3.5.3.8 Grated Arrays

Grated arrays, such as the balloon supported type tested by General Mills (ref. 3.4.12), are also restricted to fixed angles between the receiving direction and the transmitting direction. They are additionally much more restricted in bandwidth. The coherent scattering system tested by General Mills in the reference utilized a nonresonant grated array. This type of array is less sensitive to frequency changes than the dipole array tested earlier by General Mills. Both the dipole array and the nonresonant grated array systems have the advantage of providing a coherent communications path with a relatively constant amplitude and phase characteristic, and are free of scintillation.

The bistatic scattering cross section of a nonresonant grating is:

$$\sigma = \frac{4A_s^2}{\pi\lambda^2}$$

where, A_s is the physical cross section of the array, including the open spaces between the reflective sheets. The peak gain of the scatter is defined as:

$$G_s = \frac{\sigma}{A_s} = \frac{4A_s}{\pi\lambda^2} .$$

In comparison with the peak gain of an antenna of rectangular aperture, the gain of the scatterer is about one order of magnitude lower ($1/\pi^2$). This can be explained by the fact that the grating has other strong lobes, transmissive as well as reflective, besides the one which is utilized. Theoretical gains of about 10.6 db were calculated for the experimental grating. The results of the tests of this grating showed a receiving propagation path loss of 12 to 14 db greater than the free space value, after the diffraction grating reached 10,000 feet altitude. A calculation of the tropospheric scatter propagation path loss resulted in a value almost 16 db below that due to the grated array scattering.

3.5.3.9 Van Atta Retrodirective Arrays

The Van Atta reflector array is an array in which the elements are interconnected to reradiate energy back in the direction of arrival. This type of array reflects over a wider angle than the typical corner reflector, but is sensitive only to incident waves in the frequency band of and having the polarization of the dipoles. Although the Van Atta array is capable of reflecting a wave incident at any angle from end-fire to broadside, its performance is limited in practice by the directivity of the radiators.

The Van Atta array tested by Sharp and Diab (ref. 3.5-24) maintained a high scattering cross section over a 50 percent larger angle than the typical corner reflector and, for the same scattering cross section, the Van Atta array is somewhat smaller in cross sectional area. This array can be modified to reflect a wave of any polarization by arranging that half the radiators be vertically polarized, and half horizontally polarized or by using circularly polarized radiators. The frequency band of operation can be made quite large by the use of wideband radiators such as the conical helix or other frequency-independent antennas.

A numerical investigation by Larsen and Nielsen (ref. 3.5-25) showed good agreement with Sharp's experiments. They also found that a conducting plate behind the dipole system causes a rise in the level of backscattering normal to the plane of the reflector and a highly increased 5 db response angle, while it has the disadvantages that the backscattering cross section decreases very fast for angles of incidence greater than 60° to the normal of the reflector.

Most of the minor fluctuations in gain of the array at varying angles from the normal are due to the reinforcement or cancellation of the Van Atta retrodirective response by the beam scattered from the antenna array elements. When the Van Atta array is used in an active system this scattered beam makes a negligible contribution to the array pattern.

Gains of 20 db are not difficult to obtain, with the gain dependent upon the number of antenna elements making up the array. An array of 196 elements (14 x 14) is expected to provide a gain of 26 db for an active satellite system. Table I of Gruenberg and Johnson (ref. 3.5-28) gives the gain of a 300 element array as 29 db, a 1000 element array as 34 db, a 3000 element array as 39 db, and a 10,000 element array as 44 db.

3.5.3.10 Semi-Active Relays

Semi-active (or quasi-passive) relays make use of active elements either to enhance the effective cross-section of the reflector system, to modulate the reflected signal, or to amplify, as well as to modulate, the incident signal using ground power. Active relays will also be discussed which require a small amount of on-board power.

One of the simplest quasi-passive relay systems was described by Gruenberg and Johnson (refs. 3.5.26 - 27 - 28). It uses a retrodirective antenna of the Van Atta type which is modulated by solid state devices inserted in each path connecting conjugate array elements. The system power consumption can be reduced to the point where ground-supplied power may be considered. The transmission paths from ground to the relay and from the relay to the second ground station are considered separately. The link from ground to the relay is a straightforward one-way transmission system and is not critical. This link is operated by a modulated signal from any direction within the field of view of a simple dipole antenna. This antenna connects to a receiver which detects the signal from the ground. The detected signal is used to modulate the Van Atta array.

This system reduces the beamwidth requirement of the Van Atta array by using a separate receiving antenna or group of antennas. The gain of the Van Atta transmitting array may be substantially increased in inverse proportion to the beamwidth. By eliminating the requirement for the beamwidth of the Van Atta array to include both receiving and transmitting ground stations, the gain may be greatly increased over the conventional Van Atta array. The performance of this array at X band may be comparable to an orbiting spherical reflector having a 3000 ft. diameter.

A more recent satellite data transmission system, described by S. André of Sylvania Electronics Systems (ref. 3.5-29), uses a small amount of on-board primary power to operate modulators and amplifiers of low power. Two sets of array elements are used on this satellite, one for receiving and one for transmitting, which are interconnected to function as a single adaptive array. The set of receiving elements is interlaced with the set of transmitting elements to permit both arrays to occupy a common surface area of the satellite. Several methods are used to isolate the two sets of elements and, thus, to enhance the system stability by decoupling the amplifier input and output. First, the receiving set of elements is orthogonally polarized with respect to the transmitting set of elements. Next, a frequency offset is used in conjunction with diplexers, to further isolate the input from the output. Finally, the adjacent elements of the receiving and transmitting arrays are oriented in a manner that provides minimum coupling without an undue increase in array aperture.

Prior to the initiation of data transfer the satellite power is off, preventing unauthorized use of the satellite. A ground terminal, on the portion of the earth visible to the satellite, transmits a "turn-on" command to the satellite. The satellite command receiver tests the received signal and, upon receipt of a correctly coded command from the ground, turns on the satellite power supply. The command receiver antenna consists of a portion of the adaptive array or possibly of a separate antenna associated with the telemetry or command control system.

After sending the initial command, the ground terminal transmits an unmodulated carrier to the satellite at a frequency within the bandpass of the satellite amplifiers. After reception in the satellite, the signals from the array elements are amplified and translated in frequency by the satellite local oscillator frequency. The adaptive array then retransmits this signal back to the ground terminal, realizing the full array gain.

After the system is completely aligned, a second command sent to the satellite starts the data readout to the satellite modulator which frequency modulates the satellite local oscillator. The modulated signal is applied to the received carrier via the mixers. The adaptive array continually redirects the received beam back in the direction of the transmitting ground station which transmits a cw signal during data readout.

Subsequent to data readout, appropriate commands can again be sent to the satellite to terminate the link and disable the adaptive antenna. In a hostile environment, complicated authentication codes may be required to prevent capture of the system and loss of data. In a jamming environment a large dynamic range in the satellite is advantageous.

The adaptive property and gain of an adaptive array are realized only during transmission from this array, thus this full gain is not obtained during up-link data transmission. This is usually not a serious problem since large ground terminal transmitter powers are available. The full gain of the adaptive array is available during the down-link data transmission to reduce the satellite transmitter power and the primary power requirements by 90% or more.

This type of semi-active satellite data transmission system could be modified if additional primary power is available on board the satellite. This modification involves the use of a separate active adaptive antenna array system for receiving the up-link signal from the ground station. An adaptive array system for receiving only has been designed by Gangi (ref. 3.5-30), using a separate phase-locked loop for each antenna element. The acquisition time for the array, or whether it will acquire at all, is dependent upon the signal to noise ratio in each antenna element. A minimum S/N ratio of about 10 db was chosen to ensure that noise spikes larger than the peak signal occur less than 0.1 percent of the time. The S/N ratio after acquisition improves substantially, depending on the number of elements in the array and on other factors. This type of antenna array can scan and acquire rapidly, is automatically adaptive to signal strength and to noise spectral density, and is self-focusing. Since it requires a separate mixer, oscillator, phase detector, phase shifter, and loop filter for each antenna element, it has the disadvantage of requiring a substantial amount of primary power from the vehicle.

A program has been underway for several years at Ohio State University (ref. 3.5-15), to study unified designs incorporating RF circuitry or nonlinear elements as integral parts of antenna configurations, to perform such functions as multiplying, amplifying, mixing, phase shifing, tuning, and oscillating. One of the applications is for an electronically steerable receiving antenna array. A detailed description of the digital steering control circuitry was given. A description was given also of a wide-band phase detector for use with an integrated cavity-backed slot "antennamitter". Further information has been given in two earlier Ohio State University reports (refs. 3.5-31, -32) on other techniques for integrating solid-state circuitry into antennas.

3.5.3.11 Conclusions on Passive and Semi-Active Repeaters

Several types of passive reflector systems may be useful for temporary replacement of the primary high altitude radio relay system. Most of the passive reflector systems have a low gain at UHF and microwave frequencies and even less in the VHF frequency range. The resulting system transmission path loss is excessive for VHF tactical equipment and is marginal for the UHF and microwave point-to-point line-of-sight links. Several of the passive reflector systems, such as chaff and artificial electron clouds have sufficient system gain to be useful. Chaff reflectors may be emplaced quickly by high altitude rockets to provide a short duration temporary replacement for a ground relay station that has been destroyed or has failed. Chaff could also be used to establish a new temporary point-to-point relay path during a short duration ground tactical operation.

Artificial electron clouds may also be emplaced quickly by high altitude rockets to provide a temporary reflecting area. The duration of the artificial electron cloud may be made somewhat longer than the chaff cloud (60 minutes duration or more may be obtained at altitudes over 115 kms) but only for frequencies of 20 MHz or below. Both the effective cross-section and the duration drop-off substantially above 40 MHz and result in very poor efficiency for the UHF and the microwave frequencies. The resulting poor agreement between the best reflecting frequency of 20 MHz for the artificial electron clouds and the required high ground station gain, obtainable only at 200 MHz to 10 GHz, makes this technique rather ineffective.

Spherical reflector balloons have too low gain, are expensive and difficult to launch, and will remain in an effective position only for 6 to 8 hours or less. They also take quite a while to launch and get into position. Thus, they are a poor solution to the high altitude radio relay system problem.

The retrodirective types of reflectors, such as corner reflectors, Luneberg lenses, and Van Atta retrodirective arrays are monostatic and cannot be used unless the angle between the receiving path and the transmitting path is quite small. To keep this angle small, the distances from the receiver to the reflector and the transmitter to the reflector will be probably much greater than the direct distance from the receiver to the transmitter, with a resulting excessive transmission path loss.

Orbiting dipoles, such as the type used in the West Ford experiment, have such low gain that only a high-gain low-noise tropospheric scatter relay system would receive a usable signal from the orbiting dipoles. The signal level would be far below the level required by point-to-point line-of-sight relay systems.

Grated arrays would have somewhat better performance than the spherical reflector balloon. These array types would require free or tethered balloons as supporting vehicles and thus would have all the cost and logistics disadvantages of balloon systems, as well as the added complexity of the grated arrays.

Semi-active relays, using one or two Van Atta retrodirective antenna arrays, would provide sufficient gain for most of the UHF and microwave point-to-point relay applications of the high altitude radio relay systems. The primary power requirements would be quite moderate and could be provided easily on unmanned vehicles, such as balloon. The antenna arrays could be designed also to provide a substantial gain with no orientation requirements in azimuth. The amount of gain and power output of the semi-active relay may be adapted to the amount of primary power available on the vehicle. The primary power supply on board a free balloon would probably be quite limited, due to the weight of batteries. If a drone or manned aircraft is used for the airborne vehicle, considerable power could be supplied to the semi-active repeater system. These semi-active systems thus seem to be an excellent engineering compromise for a passive or semi-active repeater system. A selected bibliography on passive and semi-active repeaters has been included in Section 3.6.

3.5.4 RADA Compatibility

The ECOM RADA (Random Access Discrete Address) program is directed toward development of a division area UHF radio equivalent of an automatic telephone exchange (ref. 3.5-33). The switching function is distributed among the subscribers, so that each basic subscriber unit (BSU) may select any other such unit, or may operate through a retransmission unit (RTU) which provides extension of the BSU range and interconnecting with wireline or radio facilities. The currently anticipated application is to divisions, combat battalion headquarters and combat support company communications. The RADA technique permits communication while the division is moving, and requires a minimum of set-up time to re-establish the complete communications network. It should be noted that RADA as now planned does not concern replacement or augmentation of tactical FM network functions.

There are several areas in which the RADA-HARR interface may be considered:

1. Use of basic subscriber units for interconnection with HARR platform.

2. Use of HARR platform for elevated retransmission unit locations.

3. Use of HARR multichannel repeater for interconnection of distant RTU's.

4. Use of RADA signalling techniques in tactical backpack radio application.

The first application would provide interconnection of the division area network with the combat groups served by the HARR repeater. Use of more than one BSU at the repeater platform may not be feasible in view of interference between the units. Multichannel interconnection with tactical networks may require the use of a RTU equipment. The nature of most tactical communication is such that the connection of the division area network and tactical networks may be of doubtful value.

The second area for RADA-HARR application is the shared use of the HARR platform for the RTU. Use of an elevated RTU has been considered in a phase of the present RADA program (ref. 3.5-34). The results of this Martin-Marietta RADA airborne relay study show that simple repeaters and frequency translators have been found to be unacceptable for use with their RADA system. The main problem was possible interference with established system messages. They conclude that logic and channel search procedures must be included in the RADA airborne relay. They recommend a reduced capacity retransmission unit (RTU) with minimum special functions as the best airborne relay configuration for RADA. The special functions of conference calls, warning broadcast, data capability, etc. were considered unnecessary. Because of the elevation of the airborne relay, it has the added disadvantage that it must contend with the RADA activity in adjacent divisions as well as its own division; therefore, its channel search time may be increased significantly.

The areas in which compatibility should be evaluated are:

a. Ground coverage areas for RADA RTU and HARR

b. RF compatibility of RTU and platform air-ground UHF equipment.

c. Physical locations on platform for RTU and HARR antenna assemblies.

d. Volume, weight, and power sharing with HARR

e. Operator requirements.

These factors have not yet been considered, pending further definition of HARR and RADA requirements.

In using the HARR multichannel relay as an interconnecting link between RTU equipments, the HARR equipment and its corresponding ground terminals simply supply 4-wire duplex telephone circuits, which will be directly compatible with the RADA terminal equipment. This use of the HARR is identical to that provided in interconnecting distant wireline or radio circuits with an elevated relay equipment.

The last area of application of the RADA technique is that of providing a multiple access capability for tactical networks now served by limited-subscriber FM networks. Questions to be answered here include:

a. Is there a need for direct access between each subscriber in existing FM networks?

b. Are bandwidth requirements of RADA compatible with jungle propagation restrictions on operating frequency?

c. Does a RADA terminal necessarily require full duplex operation?

d. Is the RADA modulation format compatible with clutter return characteristics of jungle or mountainous terrain?

e. How does jamming and interference performance compare with existing techniques?

f. How much is compatibility with existing FM pack-set and vehicular equipment worth?

g. Can weight, battery life, initial and operating cost and performance compete with FM?

h. Is there a threat of use by the enemy of a captured RADA set to elicit automatic subscriber set responses for direction finding and fire control?

It is evident that the automatic switching implicit in the RADA technique provides a more rapid person-to-person connection capability than the attended HARR repeater envisioned, but whether the person-to-person mode is useful and necessary for coordinating tactical operations on a company, platoon, or squad level basis is doubtful.

A review of earlier RADA techniques was conducted in an effort to determine whether the modulation modes were compatible with the tactical radio environment. A resulting bibliography of RADA and multiple access references is included in Section 3.6.

3.5.5 Review of Contemporary Relay Efforts

3.5.5.1 General

The following brief paragraphs describe several contemporary relay efforts, some of which have been cited elsewhere in the report. These efforts are directed at several different applications and have met with varying degrees of success.

3.5.5.2 Motorola, F_1-F_1 Relay

A modified AN/PRC-25 has been applied to F_1-F_1 relaying by Motorola, Inc. for the Army Avionics Laboratory (ref. 3.5-35). Switching is at a 37.5 kHz rate and a 33% transmit duty cycle is used. The referenced report indicates the necessary modifications to the AN/PRC-25. Satisfactory operation was obtained in the laboratory. Evaluation in a helicopter platform had not been completed at the last report.

3.5.5.3 Litcom "Junglebuoy"

The "Junglebuoy" is a helicopter-type container developed by the Litcom division of Litton Industries for a variety of air-drop applications (ref. 3.5-36). Contra-rotating helicopter blades permit accurate and controlled positioning of the relay or beacon package in the jungle canopy.

Three simplex relay configurations have been tested (ref. 3.5-37) designated A, B, and C:

A:	VHF	FM/FM relay
B:	VHF	FM/AM relay
C:	VHF	AM/UHF AM

Power output of each unit is 5 watts, and each functions as a frequency translating relay. A field test of the "A" version in Viet Nam (ref. 3.5-38) indicated that the range of ground-based AN/PRC-25 and AN/VRC-12 was reduced to about 65% of the non-relayed range with the Junglebuoy either at ground level or elevated 30 feet. It was concluded that the Junglebuoy in its present configuration was not suitable for tactical communications range extension.

3.5.5.4 Prodel, S.p.A. Mobile Radio Repeater

An Italian firm, Prodel, S.p.A. has developed a solid-state frequency translating simplex relay for single-channel VHF - FM mobile communication, for extending the range of patrol car radios (ref. 3.5-39). This relay uses separate receiving and transmitting antennas 100 feet apart to achieve an initial 35 db R-T isolation, in addition to the isolation provided by diplexing filters. Receive-transmit frequency separation is only 500 kHz, so design of diplexing filters with necessary rejection and low insertion loss was a considerable problem. They experienced difficulty with activation of the relay squelch (hence activation of the transmitter) by distant co-channel signals.

3.5.5.5 Sylvania Balloon-Drone Borne Repeater

Under an RADC contract, Sylvania modified an AN/PRC-71 UHF transceiver as a simplex frequency-translating UHF relay (ref. 3.5-40). Successful drone and balloon-borne tests were conducted at Holloman AFB, New Mexico. The relay package withstood operation at 80,000 feet and temperatures to -76°C. The relay provides 10 watts power output, diplexing for single-antenna operation, and 60 MHz frequency separation. Performance was generally in agreement with predictions. Fading was noted in the balloon tests corresponding to nulls in the AS-1097 antenna pattern as the relay payload swung beneath the balloon.

3.5.5.6 Pye Telecommunications, Ltd. Synchronous Stable Relay

Pye Telecommunications, Ltd. has developed a common-frequency F_1-F_1 non-switching relay for extending the range of UHF mobile communication systems (ref. 3.5-41). This relay makes use of spaced (100-150)' cross-polarized directional antennas to enable gains of the order of 120-130 db to be used. No difficulty was experienced with aircraft reflected signals. The requirements for directional antennas with considerable front-to-back ratio and for substantial spacing would preclude applications to an airborne relay.

3.5.5.7 Electronic Communications, Inc. Multichannel Relay

Electronic Communications, Inc. has reported results of air to ground 15 channel FDM-FM duplex relay tests (ref. 3.5-42), using the AN/ARC-89(V) UHF relay equipment. While the channel capacity is normally 12 channels a second multiplexer was employed to insert 3 channels from 0.3 to 12 kHz. Reliable operation over ranges of 210 nautical miles from air to ground and 400 nm from aircraft to aircraft has been demonstrated.

3.5.5.8 Tactical Air Command RRQ-5F Relay Pod

The Special Air Warfare Center of the Tactical Air Command has developed an aircraft-mounted relay pod containing two AN/PRC-25 transceivers connected in the frequency-translating mode. The report (ref. 3.5-43) indicates that the operation of the relay pod was satisfactory, and suggested remote frequency selection from the cockpit as the principal modification.

3.5.5.9 Lincoln Laboratory Tactical VHF Relay

Lincoln Laboratory has built a switching-type F_1-F_1 relay package, for use with VHF tactical radio equipment of the AN/PRC-25 variety (ref. 3.5-44). A switching rate of 20 kHz was used, with a 20% transmit duty cycle. The relay was demonstrated over a 13 mile circuit, with the relay package in a helicopter at 5000 feet altitude at mid-path. The antenna pattern from the helicopter was noted to have 12 db nulls, which caused noticeable fading. Interference from other services in the frequency range employed was noted, as was self-jamming due to PRC-25 overmodulation.

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SECTION 4

PLATFORM SYSTEMS

4.1 OBJECTIVE

The objective of the platform analysis is to select at least three preferred platform candidates to be combined with the recommended repeaters and form the initial HARR system alternatives.

4.2 PLATFORM STUDY REQUIREMENT

The platform analysis as outlined in the HARR Study Technical Guidelines, 14 April 1965, is based on a cost and operational effectiveness study involving airborne platforms conceived during the course of the study or those categorized as:

a. High-altitude balloons
b. Rocket-launched platforms
c. On-station aircraft
d. Synchronous communication satellites

As the result of recommendations made at joint ECOM/HARR study team meetings, activity undertaken during the first half of the study concentrated on an initial configuration developed from existing inventory platforms and repeaters. In keeping with this recommendation, only those platforms are included which meet initial system configuration requirements. Any exclusion, however, was possible only when investigation disclosed that at least a year of research and development was necessary prior to procurement.

4.3 APPROACH

The approach used in selecting the three or more platform finalists was: investigate all likely prospects; eliminate enough of these to make a manageable number on the basis of procurement and operational considerations; and narrow down to the final three or more by entry into a cost-effectiveness trade-off. Since a stipulation of the study was that the feasibility of the use of random military aircraft as repeater-bearing platforms be investigated, this analysis was undertaken in addition to the platform selection.

4.4 RANDOM* AIRCRAFT SORTIE DISTRIBUTION ANALYSIS

An initial task in the platform analysis was to test the feasibility of placing a repeater package on all available South Viet Nam U.S. military aircraft.

A critical problem in the pursuit of the "random military sortie distribution" approach was to find sufficient South Viet Nam aircraft flight operation data to make the analysis reliable. First, effort was expended in seeking out Viet Nam aircraft sortie simulation models that could be adapted to the desired requirement. One of these models was found at Mitre Corporation in Burlington, Massachusetts. A specific investigation of this model disclosed that in its existing form it could only handle U.S. Air Force aircraft and that the introduction of Army and Navy aircraft parameters would require additional coding. Therefore, other methods of obtaining reliable distribution values had to be explored. The most promising of these appeared to be a special probability analysis. Obviously, the credibility of the results is only as good as the data used. Work then concentrated on finding reliable Vietnam sortie information that was in sufficient quantity and distribution to make the conclusions significant. Such a data source was found in the Pacific Air Force Management Summary, which is issued quarterly.

Since the classification of this sortie data is SECRET, the distribution computations and results obtained directly from the classified material are not included herein. The restricted data used gives destinations, origins, sortie rates, operational times, typical mission profiles, and considerable pertinent information on ARVN theater military aircraft operations during the past two years. Only that portion of the analysis and the results that have been authoritatively determined as unclassified are included in the aircraft distribution discussion in the following paragraphs. All data were for daylight operations only.

4.4.1 Results. Figure 4-1 is the probability map for random aircraft to provide a platform where needed during an assumed 12-hour daylight operating period. The values adjacent to the contour lines are the probabilities that a ground unit will be within range of any airborne platform at a randomly selected time. It appears that random aircraft will not serve the purpose of HARR except in the delta where the C-123 alone ensures availability of a platform. This is due to altitude and flat terrain and assumed high-altitude special operations. The relatively "high coverage" ridge from Pleiku to Phu Bai results from the assumption that strikes were channeled via that route.

*"Random" means randomly distributed as to place or time.

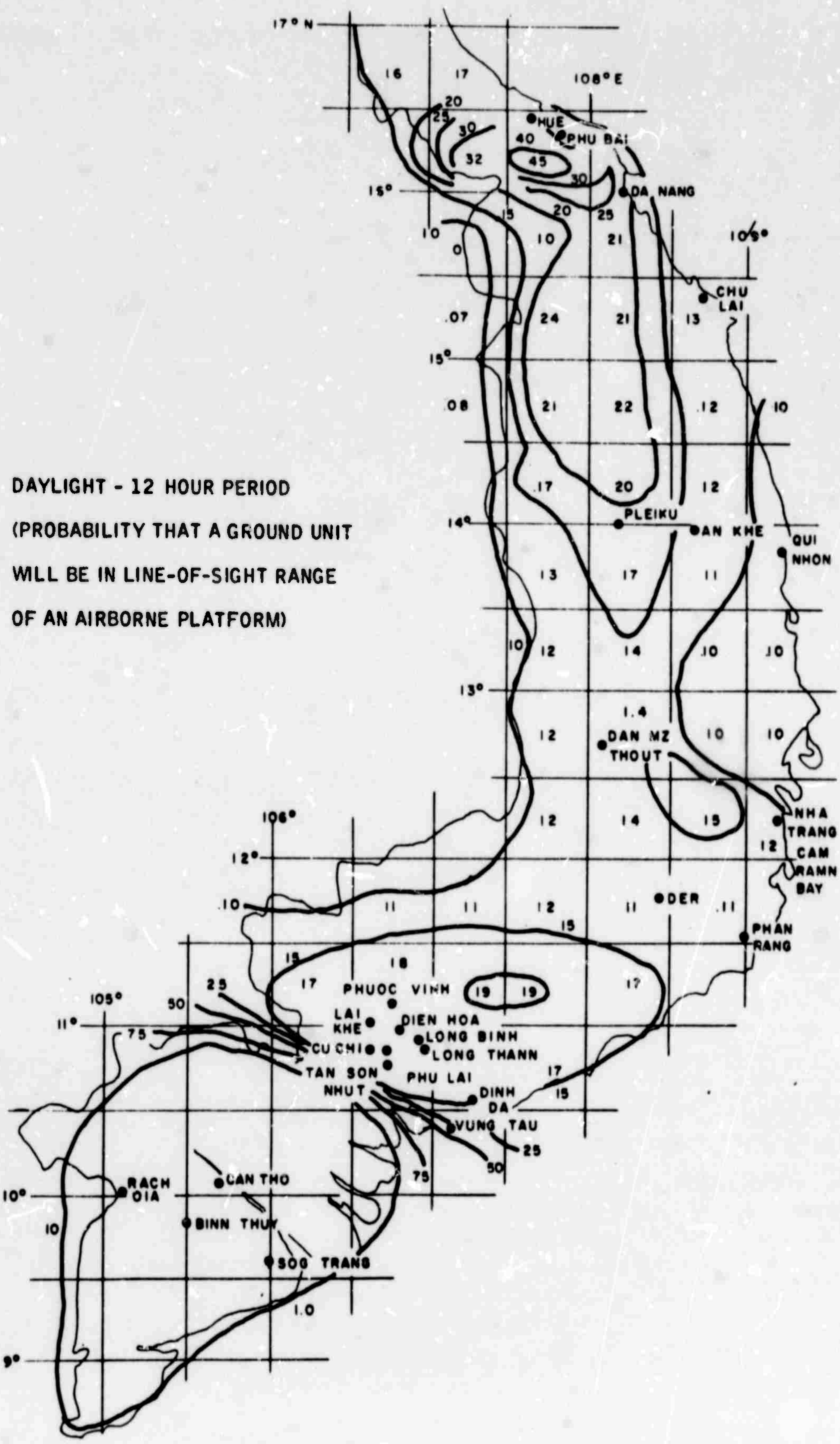


Figure 4-1. Airborne Relay Coverage of Viet Nam

4.4.2 Methodology. The effectiveness measure is expressed as follows:

$$C_i = 1 - \Sigma_j (1 - P_{ij})$$

$$P_{ij} = K_{ij} F_{ij}$$

where

F_{ij} = the fraction of total time during which a platform of type j is in zone i. When n platforms of type j may be in zone i simultaneously:

$$1 - F_{ij} = (1 - f_{ij})^n$$

where f_{ij} is the fraction of total time spent in zone i by each of the n platforms.

K_{ij} = that fraction of the area of zone i which is covered by a platform of type j when it is in zone i.

P_{ij} = the probability that, at a randomly selected instant, a platform of type j is available to a ground station in zone i.

C_i = the probability that, at a given instant, any platform is within range of a ground station in zone i.

NOTE

The assumption of independence implicit in the foregoing is not strictly true in all cases. In those cases where the assumption is not valid, it is sometimes possible to treat the situation as made up of properly mutually exclusive events. For example, in the case of a few aircraft transiting South Viet Nam enroute to Laos or North Viet Nam for long periods on station, the times of transiting a given zone are probably not independent since one aircraft relieves the other. Accordingly, in the calculations the periods spent in a zone are added. As another example, in the case of numerous small aircraft such as FAC operating from a single base, flight paths and distinations are almost certainly not independent on a short-term basis. However, over a long period of time the distribution of aircraft locations may be nearly uniform over an appropriately selected area. The approximation introduced by making the assumption of independence is appropriate to a relatively long period of time.

4.4.2.1 Computations. This analysis makes use of data from operational bases and the aircraft which makes use of the bases. After applying the probability factors shown in paragraph 4.4.2 for C_i, the computational results were plotted on a map of South Viet Nam similar to that shown by Figure 4.1. Contour lines were drawn as isobars connecting the equal probability points. A significant part of the computations was "the cone of coverage" determined for each sortie considered. This cone of coverage was drawn from the position of the aircraft to the ground. A terrain analysis made of each portion of South Viet Nam plus the height of the aircraft determined the amount of area covered by the cone. A "line of sight" value taken from the ground to the aircraft and the range capability of the PRC-25 determined the dimensions of the cone. The percent of time aircraft would be in the vicinity gave the F_{ij} values. When there was a probability of more than one aircraft, F_{ij} became a compound value.

4.5 PLATFORM SELECTION ANALYSIS

4.5.1 Problem. A dual problem governed the treatment of platform capabilities. This was the ability to:

a. Penetrate tropical foliage
b. Avoid terrain masking

It was found that, although it would be most desirable to have a platform responsive to both problem considerations, certain candidates did not lend themselves to more than foliage penetration. As a consequence the analysis was divided into two portions: that dealing with special platforms which could primarily handle the foliage penetration problem, and that dealing with platforms which could take care of the terrain masking avoidance as well as the foliage penetration.

4.5.2 Foliage Penetration Candidates. Although the guidelines of the study prescribed a minimum altitude limit of 1,000 feet, certain platforms were examined that customarily would be put at altitudes below this height.

4.5.2.1 Tethered Balloons. Tethered balloons have been used with some success by the Army of the Republic in Viet Nam (ARVN) forces in South VietNam. The ARVN commanders have liked them for fairly fixed locations and are unconcerned about the disclosure of location due to the tether line, since their positions are already known to the Viet Cong.

The antennas used for the ARVN balloons were normally HF, and, although conventionally-shaped balloons were used, the buffeting of the platform did not present a problem until the winds became quite high. In fact, it was found that the tilt angle of the antenna had little effect on propagation up to an angle of 30 degrees.

G. T. Schjeldahl Company currently is developing a tethered balloon-borne antenna system for NATO to extend 15,000 feet above sea level. The balloon is a 70,000 cubic foot natural shape envelope (55-foot diameter) using the tether line for VLF quarter-wave antenna cable. The cable weight is 125 pounds per thousand feet of length. The high-altitude winds have restricted the on-station time of this balloon system from 40 to 80 percent.

Instead of the Schjeldahl antenna supporting device, a tethered balloon system more suited to the HARR mission would be an aero-dynamically-shaped envelope such as that shown in Figure 4-2. The shape of the balloon will enable it to maintain greater airborne stability than if it were given the more conventional pear or spherical shape. The payload package carried by the balloon indicates that it could be used as a repeater. A similar balloon system is described in DDC document AD 445 943, "Tactical Jungle Communication Study."

A disadvantage often associated with the tethered balloon is its hazard to flying aircraft. For the HARR application, balloons would probably be flown at altitudes between 2000 to 5000 feet rather than the much higher altitudes planned for the NASA balloons. However, even at these lower altitudes a series of tethered balloons carrying hard-material payload packages would provide considerable flight crew concern.

4.5.2.1.1 Tethered Balloon Employment. Forward area employment of tethered balloons designed for the HARR mission could be at three recommended echelons. A light-weight two-channel balloon configuration could be designed to carry a payload of 48 pounds. It is estimated to cost $3,000 for platform and tether line only. This configuration would be tethered near a company command post and would be used to service patrol and squad units. The proposed altitude would be from 2000 to 3000 feet.

A second configuration might be designed to carry a six-channel, 282-pound payload. It is recommended that it be used at company or battalion headquarters and be flown at an altitude of 3000-5000 feet. Its estimated platform and tether line cost is $7,100.

The third configuration might be a 14-channel, 628-pound carrying tethered system. Its recommended tethered position would be at battalion headquarters. It also would fly at between 3000 and 5000 feet. Its estimated cost would be around $12,000. Unless a means was found for ground-based channel control, a 14-channel balloon-borne relay could very easily introduce mutual interference problems.

Balloon costs versus the payload weight are given by the curve shown in Figure 4-3.

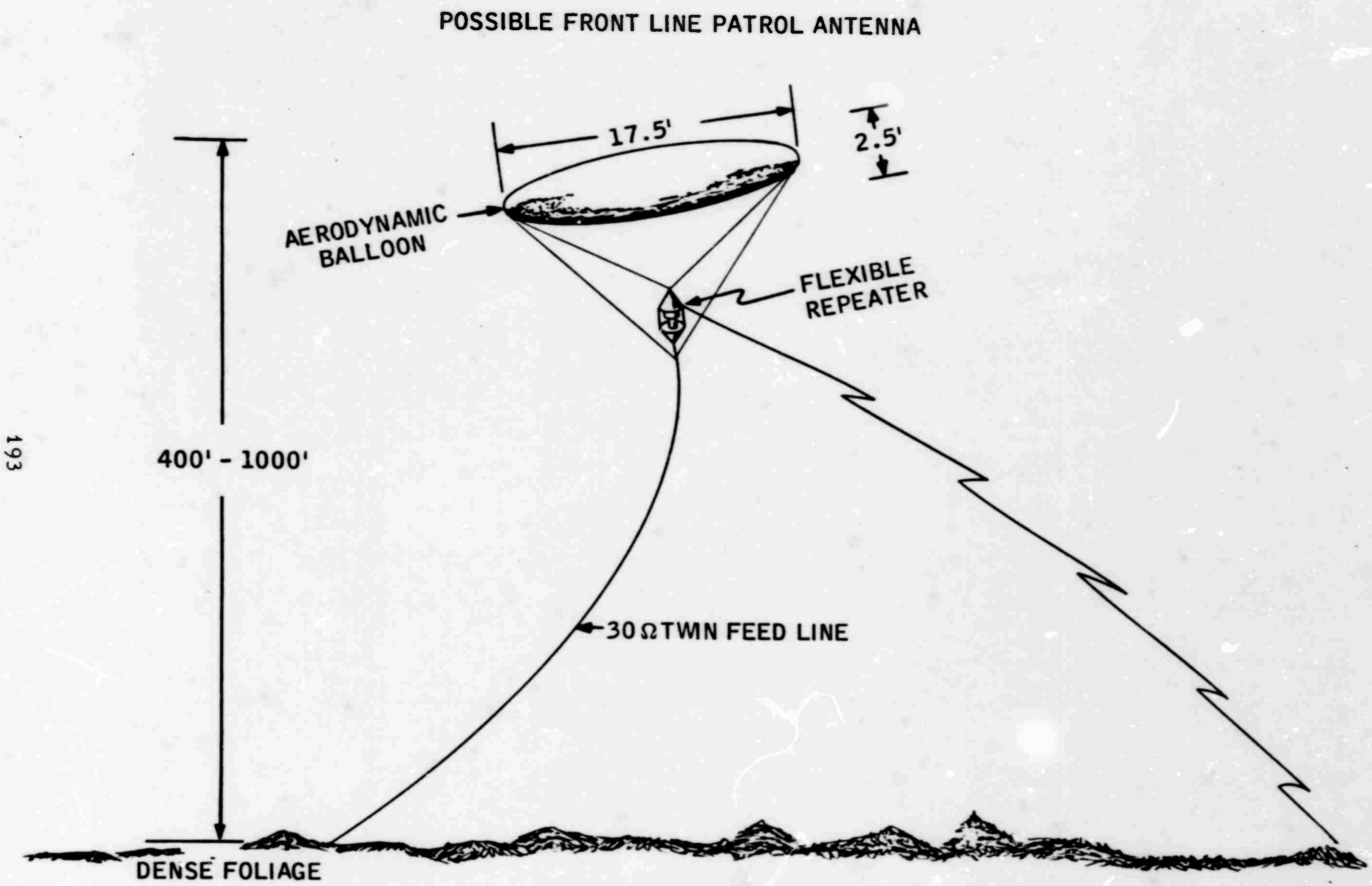


Figure 4-2. Tethered Balloon System

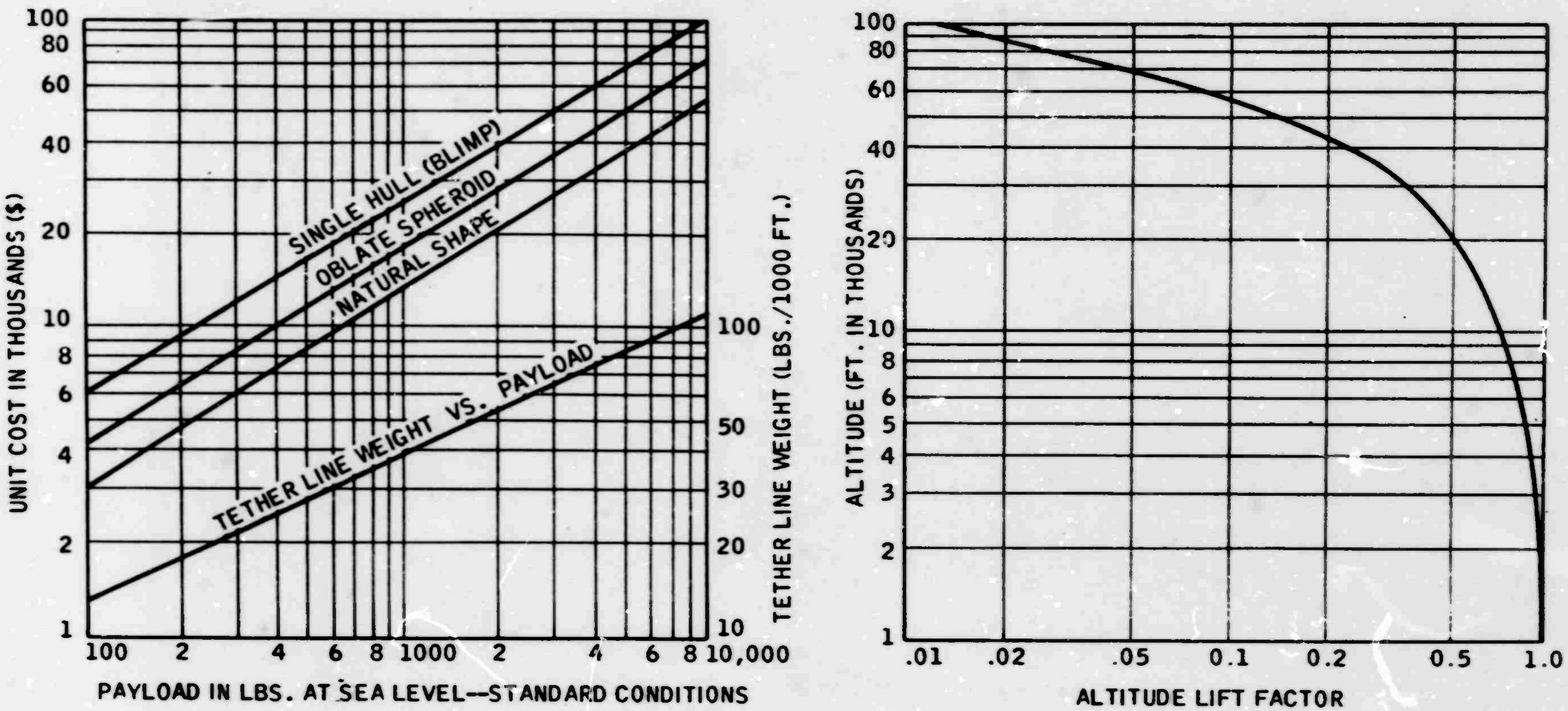


Figure 4-3. Payload vs. Estimated Cost for Various Tethered Balloon Configuration

4.5.2.1.2 Tethered Balloon Support. A 70-hour life is estimated for the batteries each recommended balloon system would carry. In each case it is felt advisable that a two-balloon arrangement be used with the relief balloon launch occurring in order that the on-station balloon can be brought down without a break in the relay service. In this case a timing device would have to be used to make sure both repeaters were not active at the same time. A one-hour turn-around time is estimated on the assumption that at least at the company level the batteries would be circulated by airlift. A critical problem encountered during the ARVN tethered balloon experience was the loss of balloons and their payload due to breaking or snagging of the tether line in high winds. This would mean that a fairly large replenishment of balloons, repeaters, and line should be kept on hand.

A reference used to determine the balloon configuration and tethering characteristics is the paper, "Capability of Captive Balloon Systems," given by J.A. Menke at the 1963 AFCRL Scientific Balloon Symposium.

The greatest problem in forward area support of a balloon would probably be in providing for the necessary hydrogen or helium. A balloon capable of supporting a 100-pound payload at the higher altitudes required about six cylinders of helium which weigh about 1100 pounds. The use of the hydrogen generator AN/TMQ-3 would considerably lessen the logistics problem, but its use is both time consuming and dangerous.

Aside from the gas supply equipment, the ground support required to operate the balloon platform would be the tether cable, winch, ground plates, and ground handling and protection cloths needed for the inflation gas. If hydrogen is used, the ground equipment might be provided to manufacture it from chemicals that have been brought in, but the advantage of this method of supply will have to be weighed against the use of a highly combustible gas.

4.5.2.2 Treetop Relay Platform. The treetop relay platform consists of a gas-inflated structure designed to bear on the generally dense and continuous upper surface of tropical vegetation and support a 50-pound relay payload at its center.

4.5.2.2.1 Description. The platform structure (see Figure 4-4) is circular in shape, twelve feet in diameter. The tubular structure has an 8.5-inch diameter outer rim and a 12-inch tube inner hub in the form of a torus which encircles the payload at the center. Eight tubular (spoke) beams between the rim and hub provide stiffness to the platform for bridging bearing voids within the 12-foot span. The top of the platform is a flat sheet covering the full circle and bonded to the tubular structure. Two cylinders containing 2 pounds

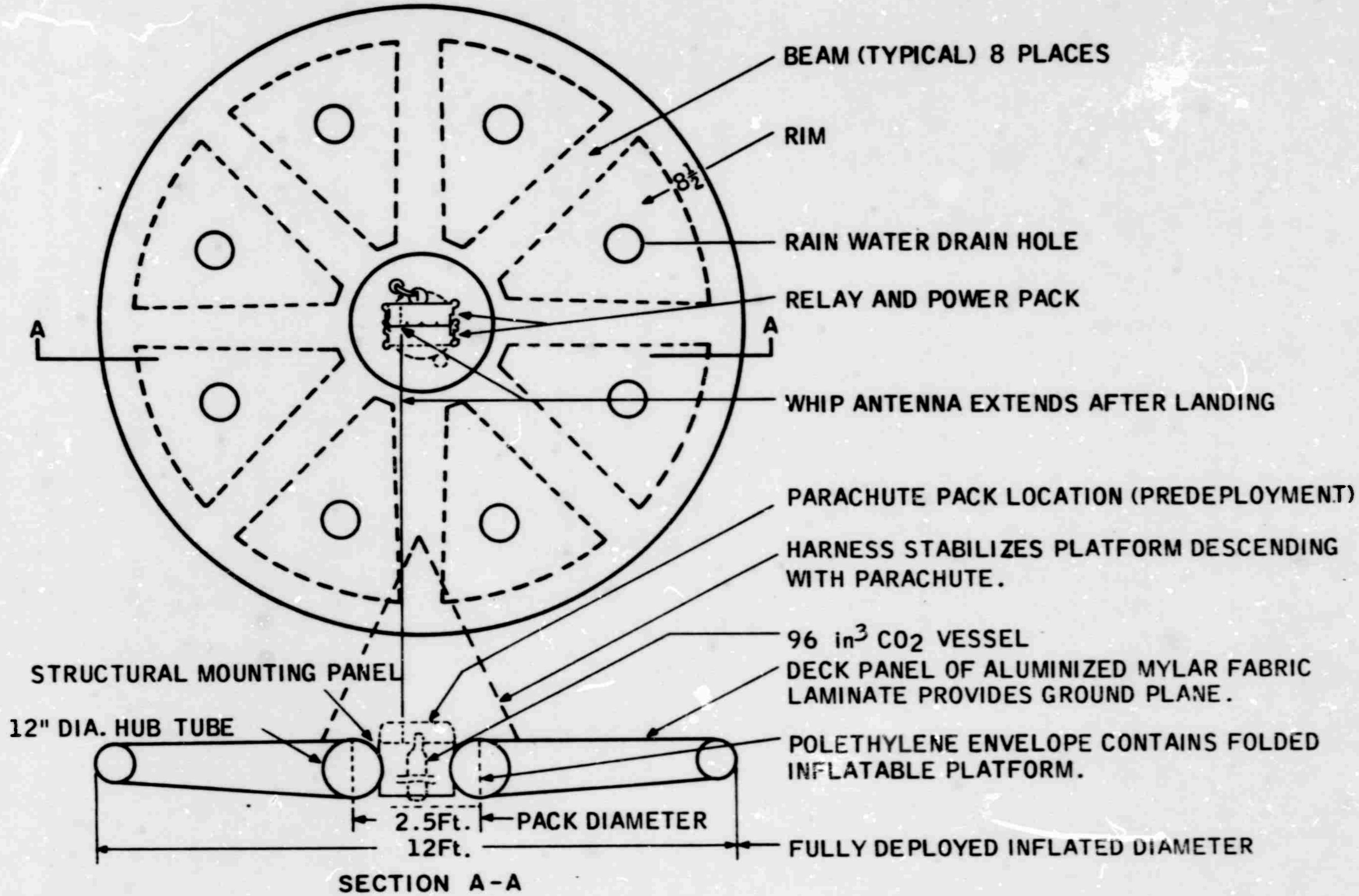


Figure 4-4. Treetop Platform Configuration

each of CO_2 gas (at approximately 1800 psi) mount adjacent to the relay assembly. Valves, triggered by the pull of a lanyard, exhaust the stored gas into the 43-cubic-foot volume of the platform for inflation.

The radio sets and CO_2 vessels mount directly to a 30-inch diameter hard panel which bears on the inner torus. This panel also serves as the top of the undeployed packed system during storage and delivery. The flexible portion of the platform folds and is packed into the annular space between the 30-inch outer diameter and the relay and inflation hardware at the center, to a 15-inch depth. A thin, frangible plastic case contains and protects the folded flexible portion of the platform assembly during storage and delivery until inflation pressure is applied for deployment. If a parachute is used, it is contained in a deployment bag atop the relay mounting panel.

Modern strong imporous balloon materials are used in the inflatable structure. A nylon fabric, mylar film laminate, is recommended. The top sheet is of similar material, but with an aluminized surface to provide a ground plan for the relay system. Based on use of the above materials, a flexible structure of 7 pounds is estimated. A total weight for the system is itemized below:

Inflatable structure	7.1 pounds
CO_2 gas (2.05 per cyl.)	4.1 pounds
Two 96-inch^3 cyl. and valves	12.9 pounds
Mounting panel and brackets	4.0 pounds
Relay, antenna and batteries	50.0 pounds
Parachute and pack	2.2 pounds
	80.3 pounds

The stowed system ready for deployment is 30-inches in diameter and 15-inches high occupying 6.2 cubic feet.

4.5.2.2.2 Deployment. Two methods of deployment are considered: aerial delivery and helicopter deployment. If the tree canopy is consistent and compatible with the bearing area of the platform, the air-drop delivery will provide rapid and efficient deployment. Stations can be at selected points (identified on a map) to be traversed by the cargo aircraft. A series of treetop relay stations then would be static-line deployed in a timed sequence. Airdrop may be performed at any suitable altitude (1500 to 5000 feet or higher), under good or poor visibility conditions.

The deployment sequence (Figure 4-5) starts with the release of the 80-pound package from the aircraft, followed by static line deployment of an 11-foot diameter ringslot parachute. As the parachute starts to inflate, the opening and deceleration force pulls the lanyards between parachute riser

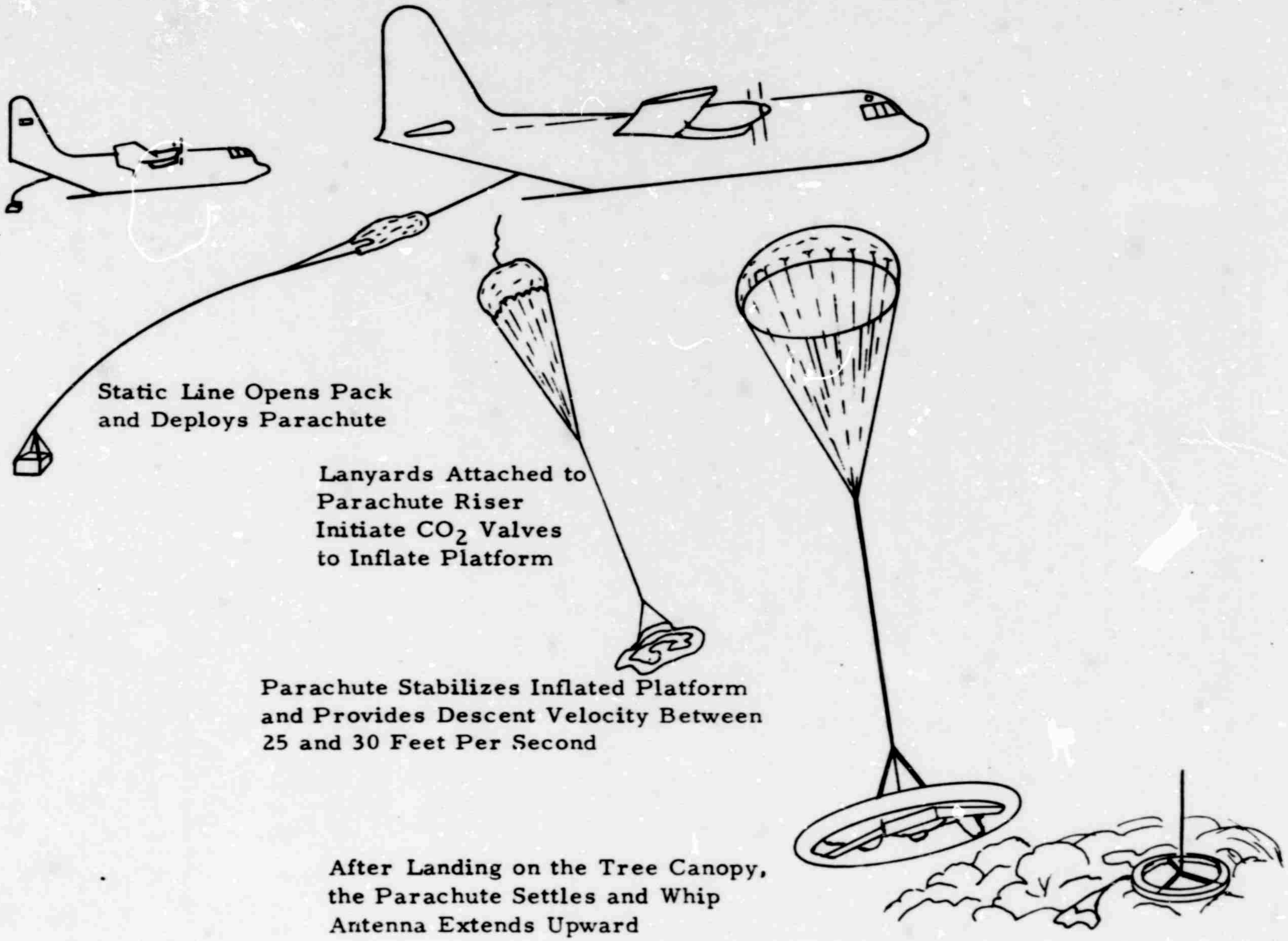


Figure 4-5. Treetop Relay Placement Using Airdrop Technique

and CO_2 valves at the package. The flexible platform then bursts its thin encasement shell and rapidly inflates to full size. The platform, stabilized by the parachute, descends to the jungle canopy to hold a position for operation. After the parachute settles, a timed switch operates to extend the whip antenna and energize the relay.

For an inconsistent free canopy, a deployment by helicopter (Figure 4-6) is recommended. The 78-pound package (without parachute) would be lowered on a cable below the hovering craft to the jungle canopy. Inflation of the platform should be initiated well below the helicopter to avoid instability from down-wash air currents. The platform would not be released until it had assumed a satisfactory bearing on the trees. Following release, the antenna would extend by pyrotechnic actuation; then relay operation would commence.

4.5.2.2.3 Retrieval. A battery life of 70-hours may be feasible with intermittent power to the transmitter. The relay station's usefulness is over when the power fails. Therefore, retrieval and replacement may be feasible. A retrieved relay station can be refurbished simply by recharging batteries, recharging CO_2 cylinders, resetting timers, replacing pyrotechnics and repacking the assembly in storage and deployment status.

4.5.2.2.4 Cost. Based on life raft production cost data, the platform system without relay and batteries should be about $420 each.

4.5.2.2.5 Forward Area Employment. Employment of the treetop relay platform is felt to be most effective at the company level. Improvement in transmission range made possible by the treetop elevation of the platform is not known. Dr. David Sachs of General Research Corporation has stated that because a system of this type could take advantage of the favorable propagation path that exists above the treetop canopy, a definite improvement in range transmissions from the ground can be expected.

Depending upon the extent of the anticipated ground-to-platform transmission range, a treetop platform would be placed at a favorably-located position in the vicinity of a planned ground activity. Another platform would be placed near company headquarters, and signals picked up by either repeater would be amplified and relayed to the companion platform; here it would be amplified again and transmitted to the ground.

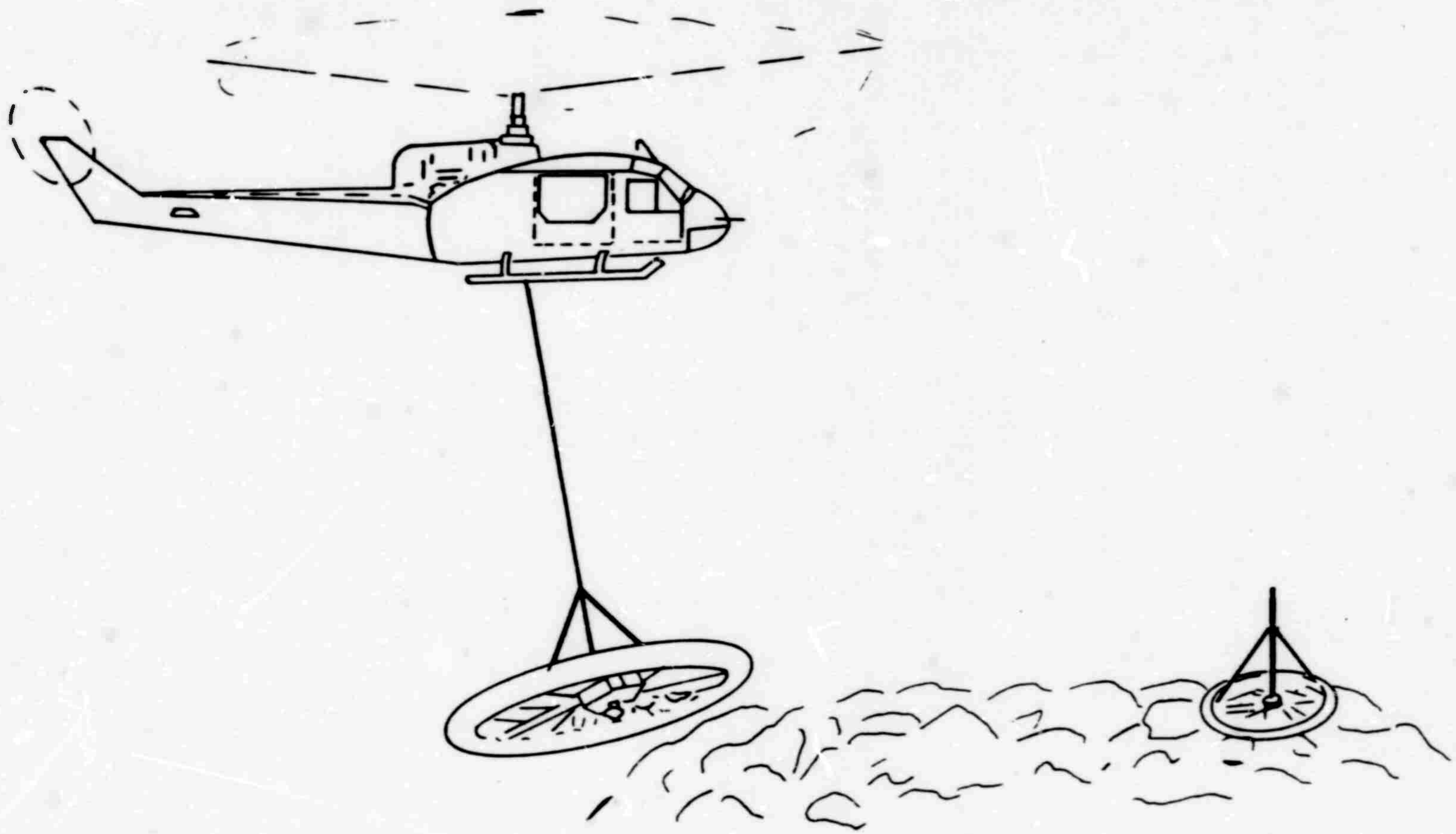


Figure 4-6. Treetop Relay Placement Using Helicopter

4.5.3 Candidates for Avoiding Terrain and Foliage. Platforms to overcome both the terrain and foliage problems are characterized by their high-altitude airborne capabilities. The initial platform list which included a large number of entries is not included in this report. The aircraft portion lists 64 manned, fixed-wing military vehicle types, 24 manned rotary-wing military vehicle types, 7 fixed-wing military drones, 3 rotary-wing drones, and one rigid-wing craft. In some instances, non-military aircraft were investigated, but because of the problems associated with their use in military service, they were dropped. More than thirty missiles, rockets and satellites also were listed. For each of these (as well as for the aircraft), the name of the vehicle, the DOD or NASA designation, the popular name, the service, primary mission, typical performance or loading, availability, and other vital statistics were included.

4.5.3.1 Aircraft Platforms. From the extensive list of possibleaircraft platforms, two elimination exercises were conducted.

4.5.3.1.1 HARR Aircraft First Iteration. The elimination process initially conducted was based on a broad application of what were believed to be pertinent HARR mission and operational requirements. A tentative requirements list is given as follows:

Platform payload	50 - 300 pounds
Relay channels	Single to 6
Relay type	PRC-25 or replacement
Time to deploy	3 hours
Time on station	24 hour potential
Initial HARR configuration	Helicopter, light or medium aircraft, balloons and drones
Platform deployment facility	Helicopter pad or forward area air strip
Platform flexibility	Capable of variable time and location
Deployment altitude	Deployed sufficiently low to avoid radio channel interference between Army Corps (250-mile line-of-sight separation); deployed sufficiently high to avoid ground fire
Platform support	Minimum required. No new school for training personnel
Destruct capability	Optional
Air traffic control	A consideration, but not deciding at this time

Pertinent requirements of the above list were applied, as well as operational and procurement considerations which were known to have a definite bearing on remote area employment.

The first elimination iteration was performed on aircraft in the initial platform list, Table 4-1. This work reduced the number of platforms considered for the initial HARR configuration to a more manageable preliminary list, Table 4-2. For candidates which are not suitable (or marginal), summary reasons are given by codes A through G in Table 4-2. They are as follows:

A. On-Station. The aircraft is not suitable because of speed or inability to loiter. For a few aircraft, inflexibility for high (15,000 feet) and low (1,000 feet) altitudes is the criterion.

B. Availability. For initial (i.e., initial configuration, Viet Nam, operational in 1967), this factor includes the inventory in Viet Nam, the allocable inventory elsewhere, the feasibility of reactivating retired aircraft, and manning potential. For interim and long-range, production schedules and probabilities are also considered.

C. Cost. The aircraft is too costly to operate for the HARR mission. (For some aircraft, larger than necessary for HARR, but otherwise very suitable, high costs might be offset by multi-mission potential.) Flying-hour costs are considered more important than procurement costs, particularly for excess aircraft no longer produced.

D. Mission Suitability. The aircraft is not acceptable because of payload limitations, short endurance, low level of proven/related military experience, etc.

E. Divertibility. The aircraft is in short supply for primary missions probably out-ranking HARR; hence, a less effective or more costly substitute platform is preferred.

F. Theater Suitability. The aircraft is not acceptable for Viet Nam because of logistics burdens, limitations on combat mobility, vulnerability to combat hardships, inability to operate all hours in all weather, etc.

G. Command. The aircraft is not readily operable by the Army, or by the other services for direct and complete support of Army operations.

Table 4-1. Initial Platform List

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
Douglas	A-1J	Skyraider	Navy	Attack	350 mph		Already in Viet Nam
Douglas	A-3B	Skywarrier	Navy	Attack	600 mph		
Douglas	A-4E	Skyhawk	Navy	Attack	4,200 lbs		Delivered to Navy, 1962, still in production.
Grumman	A-6A	Intruder	Navy	Attack	18,000 lbs		Delivered to Navy, 1963, subsequent orders.
Ling-Temco-Vought	A-7A	Corsair 2	Navy	Attack	20,000 lbs	Light attack. USAF order planned	In quantity production.
Cessna	AT-37D	---	USAF	Attack	3,000 lbs	Two evaluated for COIN missions	In production.
Douglas	YB-26K	Counter Invader	USAF	Bomber	750 lb bombs	Modified B-26 for counter-insurgency	Already in Viet Nam
Boeing	B-47E	Stratojet	USAF	Bomber	20,000 lbs	Being phased out	Could be made available.
Boeing	B-52F/G/H	Stratofortress	USAF	Bomber	75,000 lbs	Strategic	Already in Viet Nam.
GD/Ft. Worth	B-58A	Hustler	USAF	Bomber	Subsonic	Strategic	SAC only.
Douglas	B-66D	Destroyer	USAF	Bomber	600 mph		
NAA/LA	F-100D	Supersabre	USAF	Fighter	Mach-1.2	Modernized	Already in Viet Nam.
McDonnell	F-101B	Voodoo	USAF	Fighter	Mach-1.7	U.S. Air Defense	Might eventually be available.
GD/Convair	F-102A	Delta Dagger	USAF	Fighter	Mach-1.2	Being phased out, going to National Guard	Could be made available.

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
Lockheed	F-104C/G	Starfighter	USAF	Fighter	Mach-2	Fighter-bomber	Could be made available.
Fairchild Hiller	F-105D	Thunderchief	USAF	Fighter	13,000 lbs	All weather fighter-bomber	Already in Viet Nam.
GD/Convair	F-106A	Delta Dart	USAF	Fighter	Mach-2	U.S. Air Defense	Might eventually be available.
GD/Ft. Worth/ Grumman	F-111A/B	---	USAF Navy	Fighter Fighter	Mach-2.5	STOL capability	Tactical aircraft could be used.
McDonald	F-4B/C	Phantom	USAF	Fighter	15,000 lbs		Already in Viet Nam.
Northrop	F-5A	Phantom	USAF	Fighter	6,200 lbs	For MAP nations	Already in Viet Nam.
Douglas	F-6A	Skyray	Navy	Fighter	Mach-0.9	Prototype flew January 1951	Could be used.
Ling-Temco-Vought	F-8E	Crusader	Navy	Fighter	Mach-1.8		Could be used.
Grumman	F-11A	Tiger	Navy	Fighter	Mach-1.2		Could be used.
Lockheed	YF-12A	---	USAF	Fighter	90,000 ft	Long range interceptor	Not in production as yet.
Lockheed	WU/U-2A	---	USAF	Reconnaissance	90,000 ft		Classified - Special Mission.
Lockheed	SR-71	---	USAF	Reconnaissance	100,000 ft		No further production pending.
McDonnell	RF-4C	Phantom 2	USAF	Reconnaissance	Mach-2		In production, used in Viet Nam.
NAA/Columbus	RA-5C	Vigilante	Navy	Reconnaissance	Mach-2	All weather tactical reconnaissance	Delivered to Navy, 1965-1966.
Martin/GD Ft. Worth	RB-57F	Canberra	USAF	Reconnaissance	100,000 ft		Delivered to Air Force 1964

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
McDonnell	RF-101C	Voodoo	USAF	Reconnaissance	Mach-1.5	Strengthened for low altitude work	Used in Viet Nam.
Cessna	O-1E	Bird Dog	Army	Observation	115 mph	Also USAF Forward Air Controller Aircraft	Used in Viet Nam.
Grumman	OV-1C	Mohawk	Army	Observation	325 mph	STOL performance	Used in Viet Nam.
NAA/Columbus	OV-10A	---	Navy	Observation	4,600 lb bombs	COIN aircraft	7 prototypes, order pending.
Lockheed	P-2H	Neptune	Navy	Patrol	345 mph		
Lockheed	P-3B	Orion	Navy	Patrol	450 mph		In production.
Martin	P-5B	Marlin	Navy	Patrol	8,000 lbs	Flying boat	
Grumman	S-2D	Tracker	Navy	Anti-sub	275 mph		48 ordered in 1963.
Grumman	E-1B	Tracer	Navy	Early-warning	265 mph	Fighter direction	
Grumman	E-2A	Hawkeye	Navy	Early-warning	400 mph	NTDC C&C	Used in Viet Nam.
NAA/Columbus	T-2B	Buckeye	Navy	Training	20,000 ft		In production.
NAA/Columbus	T-28D	Trojan	USAF	Training	350 mph	For Viet Nam, Laos, Congo	In Viet Nam.
GD/Convair	T-29D	---	USAF	Training	230 mph		
Lockheed	T-33A	Shooting Star	USAF	Training	580 mph	Also DT drone director	
Beech	T-34B	Mentor	Navy	Training	190 mph		
Cessna	T-37B	---	USAF	Training	408 mph	For MAP countries	4 A/C per month through 1965
Northrop	T-38A	Talon	USAF	Training	Mach-1.2		Still in production.
NAA	T-39A	Sabreliner	USAF	Training	340 mph		Used in Viet Nam
Cessna	T-41A	---	USAF	Training	138 mph		170 Model 172's used by USAF

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
Beech	T-42A	---	Army	Training	236 mph		52 in use by Army
Douglas	TA-4E	---	Navy	Training			Delivered to Navy 1966
Douglas	C-47E	Skytrain	USAF	Cargo/Transports	7,500 lbs		
Douglas	C-54	Skymaster	USAF	Cargo/Transports	32,000 lbs		
Boeing	C-97D	Stratofreighter	USAF	Cargo/Transports	64,000 lbs		
Douglas	C-117D	---	Navy	Cargo/Transports	15,000 ft		
Douglas	C-118A	Liftmaster	USAF	Cargo/Transports	25,000 lbs		
Fairchild Hiller	C-119J	Flying Boxcar	USAF	Cargo/Transports	30,000 lbs		
Lockheed	C-121G	Super Constellation	USAF	Cargo/Transports	40,000 lbs		Used in Viet Nam
Fairchild	C-123B	Provider	USAF	Cargo/Transports	24,000 lbs	STOL modification	Used in Viet Nam
Douglas	C-124C	Globemaster 2	USAF	Cargo/Transports	74,000 lbs		Used in Viet Nam
Lockheed/Georgia	C-130 B/E	Hercules	USAF	Cargo/Transports	45,000 lbs	Drone launch and control	Still in production
G/D Convair	C-131E	Samaritan	USAF	Cargo/Transports	12,000 lbs		
Douglas	C-133B	Cargomaster	USAF	Cargo/Transports	79,000 lbs		Used in Viet Nam
Boeing	C-135B	Stratolifter	USAF	Cargo/Transports	82,000 lbs		Still in production
Boeing	VC-137C	---	USAF	Cargo/Transports	35,000 ft	Presidential transport	USAF version of 707
Lockheed/Georgia	C-140A	Jetstar	USAF	Cargo/Transports	525 mph		Not in production
Lockheed/Georgia	C-141A	Starlifter	USAF	Cargo/Transports	68,000 lbs		Used in Viet Nam
Ling-Tempo-Vought	XC-142A	---	USAF	Cargo/Transports	8,000 lbs		Still undergoing test
Grumman	C-1A	Trader	Navy	Cargo/Transports	250 mph		
Grumman	C-2A	---	Navy	Cargo/Transports	15,000 lbs		USAF delivery 1966

Table 4-1. Initial Platform List (Continued)

U.S. MILITARY AIRCRAFT

Manufacturer	DOD Designation	Popular Name	Service	Primary Mission	Typical Performance or Loading	Remarks	Availability
DH/Canada	CV-2B	Caribou 1	Army	Cargo/Transports	3,000 lbs	STOL performance	
DH/Canada	CV-7A	Buffalo	Army	Cargo/Transports	10,000 lbs	Army funding not approved by DOD	Deliveries started in 1966
Lockheed/Georgia	C-5A	---	USAF	Cargo/Transports	220,000 lbs		Still under development.
Beech	VC-6A	---	USAF	Cargo/Transports	16,500 ft		
DH/Canada	U-1A	Otter	Army	Utility	153 mph		Used in Viet Nam
Cessna	U-3B	---	USAF	Utility	233 mph		Used in Viet Nam
Aero Commander	U-4B	Aero Commander	USAF	Utility	10,000 ft		
Helio	U-5A	H-500 Twin	USAF	Utility	185 mph	STOL performance	Undergoing USAF evaluation
DH/Canada	U-6A	Beaver	Army	Utility	156 mph		Used in Viet Nam
Piper	U-7A	---	USAF	Utility	130 mph		
Beech	U-8F	Seminole	Army	Utility	239 mph		Still in production
Helio	U-10A	Courier	USAF	Utility	167 mph	STOL performance	Used in Viet Nam
Piper	U-11A	Aztec	Navy	Utility	225 mph		Available in several models
Grumman	HU-16E	Albatross	Navy	Utility	215 mph		Used in Viet Nam
Cessna	U-17A	---	USAF	Utility	185 mph		Still in production

Table 4-1. Initial Platform List (Continued)

U.S. ROTARY-WING AIRCRAFT

Manufacturers	Number	Popular Name	Ceiling (ft.)	Range (mi.)	Remarks
Bell	(47G-4A)	Trooper	13,700	324	
Bell	(47J-2A)	Ranger	15,100	268	
Bell	(206)	Jet Ranger	- -	400	1966 certification
Bell	UH-1D	Iroquois	18,000	315	Armed escort
Bell	(209)	Huey Cobra	- -	- -	Interim AAFSS
Bell	OH-135	Sioux	18,000	324	
Gyrodyne	XRON-1	Rotorcycle	7,300	56	
Gyrodyne	9H-50D	Dash	20,000	35	ASW drone
Hiller	OH-23F/G	Raven	9,500	226	
Hughes	TH-55A	- -	6,500	195	Army primary trainer
Hughes	OH-6A	- -	15,400	394	Army LOH
Hughes	XV-9A	- -	6,000	- -	Research vehicle
Kaman	HH-43B/F	Huskie	25,000	277	In Viet Nam
	UH-2A	SeaSprite	14,500	550	In Viet Nam
Lockheed	XH-51A	- -	10,100	241	Rigid-rotor research
Sikorsky	CH-34	Choctaw	4,900	280	In Viet Nam
Sikorsky	SH-3D	Sea King	10,600	625	
Sikorsky	CH-3B/C	Jolly Green Giant	7,100	500	In Viet Nam
Sikorsky	HH-52A	- -	14,100	474	
Sikorsky	CH-54A	Skycrane	11,900	253	In Viet Nam
Sikorsky	CH-53A	- -	10,400	282	
Sikorsky	CH-37	Mojave	- -	- -	In Viet Nam
Boeing	UH-25B	Retriever	5,200	355	
Boeing	CH-21A	Shawnee	6,100	400	
Boeing	CH-46A	SeaKnight	9,000	246	In Viet Nam USMC
Boeing	CH-47A	Chinook	12,400	234	Army transport in Viet Nam
Boeing	CH-113	Voyageur	10,050	690	RCAF
Boeing	HKP-4	- -	9,100	760	Swedish

Table 4-1. Initial Platform List (Continued)

U.S. VTOL AIRCRAFT

Manufacturer	Designation	Performance	Remarks
Hawker Siddeley	XV-6A Kestrel	50,000 ft	Evaluation as strike/recon. fighter
Lockheed-Georgia	XV-4A (VZ-10) Hummingbird	40,000 ft	Army evaluation
Ryan Aeronautical	XV-5A (VZ-11)	50,000 ft	Army evaluation

U.S. DRONES AND TARGET MISSILES

Manufacturer	Designation	Mission	Service	Endurance	Remarks
Beech Aircraft Corp.	MQM-61A	Target	Army	85 min.	Recoverable
Maxson Electronics	AQM-37A	Target	Navy	15 min.	Rocket power
Northrop Ventura	AQM-38A	Target	Army	30 min.	Rocket power
Northrup Ventura	MQM-57A	Surveillance	Army	40 min.	(SD-1)
Ryan Aeronautical Co.	MQM-34A	Target	Navy/	114 min.	Turbojet

Table 4-1. Initial Platform List (Continued)

U.S. RESEARCH ROCKETS

Manufacturer	Name	Designation	Payload	Ceiling	Remarks
Atlantic Research Corp.	ARCAS	ARC 29KS-336	12 lbs	40 mi	Single stage
Atlantic Research Corp.	ARCHER	ARC 35KS-1375	40 lbs	90 mi	Single stage
Atlantic Research Corp.	METROC	ARC 16KS-140	2 lbs	20 mi	Single stage
Rocket Power Inc.	HOPI	RPI 3.0KS-4000	11-1/2 lbs	50 mi	Chaff Dart
Rocket Power Inc.	JUDI	RPI 1.9KS-2100	10 lbs	33 mi	Balloon Dart
Rocket Power Inc.	RAVEN	RPI 8.5KS-1800	- -	- -	- -
Thiokol Chemical Corp.	TOMAHAWK	- -	45 lbs	100 mi	- -
Rocketdyne (NAA)	AEOLUS	315 lbs thrust	6 lbs	15 mi	(Gun launch)

Table 4-2. Reduced HARR Candidate List

Item Number	Rank (Initial) (1967)	Platform Designation	Limiting Factors (Ref. p. 202)
		Fixed-Wing Manned Aircraft	
1	1	O-1E	
2	1	P-2H	
3	1	S-2D	
4	1	CV-2B	
5	1	U1-A	
6	1	U-6A	
7	2	OV-1C	
8	2	E-1B	
9	2	T-37B	A, C
10	2	T-39A	A, C
11	2	C-47E	C
12	2	C-121G	C
13	2	C-123B	
14	2	U-3B	
15	2	U-7A	
16	2	U-8F	
17	2	U-10A	B
18	3	A-1J	
19	3	YB-26	
20	3	B-66D	
21	3	F-5A	
22	3	RB-57F	
23	3	P-3B	C, E
24	3	T-2B	
25	3	T-28D	
26	3	T-29D	
27	3	T-34B	
28	3	T-38A	A, C
29	3	T-41A	
30	3	T-42A	
31	3	C-54	C
32	3	C-117D	
33	3	C-118A	C
34	3	C-119J	C
35	3	C-131E	B
36	3	VC-6A	C
37	3	U-4B	A, B, C
38	3	U-5A	A, B, C

Table 4-2. Reduced HARR Candidate List (Continued)

Item Number	Rank (Initial) (1967)	Platform Designation	Limiting Factors
39	3	U-11A	
40	3	HU-16E	B
41	3	U-17A	

(42 models eliminated from initial 83 models)

Rotary-Wing Manned Aircraft

42	1	UH-1D	
43	1	OH-6A	
44	2	OH-13S	
45	2	OH-23F/G	
46	2	CH-34	
47	3	UH-2A	C, E
48	3	SH-3D	C
49	3	CH-37	C
50	3	CH-21A	D

(18 models eliminated from initial 27 models)

Fixed-Winged Drone Aircraft

51	1	MQM-36	

(initial 5 models eliminated)

Rotary-Winged Drone Aircraft

52	1	OH-50D	
53	2	DH-2C	

(Only OH-50D was on the initial list)

Payload capability for initial configuration (50 to 300 pounds) has not been a factor in rejecting candidates. For interim and long-range systems, greater payload requirements may be a factor. Antenna mounting requirements have not been considered critical.

4.5.3.1.2 HARR Aircraft Second Iteration Selection/Rejection. The reduction to the 53 remaining candidates still left too large a number for entry into a detailed cost/effectiveness. The candidate reduction process implemented during a second iteration is summarized in Tables 4-2 and 4-3.

Table 4-3 recommends that the 53 candidates be "reduced" initially to 17, and to 8 later in the study. The proposed reduction is on the premise that types of aircraft have common technical and operational characteristics affording gross measures of suitability, as follows:

A. Attack. The A-1 was retained, while other aircraft of this type were rejected because of limited on-station capability, high cost, lack of divertibility from other missions, etc. The A-1 is a marginal candidate, because of the same factors.

B. Bomber. Three models were retained as marginal candidates. Others were rejected because of high cost and on-station limitations, (e.g., ability to loiter at low altitudes in difficult terrain and weather).

F. Fighter. The F-5A was retained, while all others were rejected because of on-station limitations, high cost, etc. While the F-5A is considered to be a marginal candidate, analysis based on F-5A data can be made inexpensively (through access to Norair experience) with respect to the RFP's concern for HARR objectives being served by random sorties - close air support, reconnaissance, etc. Suitability of the A-1 (and, to an extent, of bombers) can be extrapolated from F-5A analyses.

O. Observation. These aircraft are suitable because of Army ownership/experience, ability to launch in an austere environment, on-station loitering capability, low cost, etc. Limiting factors may be all-weather capability, night-flying, and payload capacity.

P. Patrol. This is a unique case. P-2's are being moved from storage to special Viet Nam operations, the storage inventory is being depleted, and active Anti-Submarine Warfare (ASW) squadrons may or may not be releasing the obsolete P-2's. The P-3 successor (Lockheed's Electra) is not likely to be readily available. Both aircraft have

Table 4-3. HARR Candidate Selection Goals

Aircraft Designators				Number of Candidates		
Code	Type	User	Reduced HARR List	Final	Interim	Now
A	Attack	N	A-1	0	0	1
B, YB	Bomber	AF	B-66D, RB-57F, YB-26	0	0	3
F	Fighter	AF, N	F-5A	0	1	1
O	Observation	A, AF	O-1E, OV-1C	0	1	2
P	Patrol	N (ASW)	P-2H, P-3B	1	1	2
S	Search	N (ASW)	S-2D	0	1	1
E	Early Warning	N	E-1B	0	1	1
T	Trainer	All	T-37B, T-39A, T-2B, T-28D, T-29D, T-34B T-38A, T-41, T-42A	1	2	9
C	Cargo/ Transport	AF, N	C-47E, C-121B, C-123B, C-54, C-117D, C-118A, C-119J, C-131E, VC-6A	1	2	9
U	Utility	All	U-1A, U-6A, U-3B, U-7A, U-8F, U-10A, U-4B, U-5A, U-11A, HU-16E, U-17	1	2	12
CV	Cargo/ Transport	A	CV-2B	1	1	1
Rotary Wing (Helicopter)						
UH	Utility	A	UH-1D, UH-2A	1	1	2
OH	Observation	A	OH-6A, OH-13S, OH-23 F/G	0	1	3
CH	Cargo/ Transport	A	CH-34, CH-37, CH-21A	1	1	3
			Subtotal	7	15	50
			Drones	1	2	3
			Total	8	17	53

Notes: Users - N Navy
A Army
AF Air Force

Candidates within a type are listed in approximate order of suitability.

good on-station characteristics, particularly around 15,000-feet altitudes, and night/all-weather capability. Capacity and costs are high for HARR. However, should the HARR relay payload be expanded significantly, these aircraft qualify when smaller aircraft candidates for Quick Fix drop out. Present indications are that the P-2 should be analyzed in depth, and the P-3 considered as an alternative.

S. Search. This is also a unique case. USAF is using these Navy ASW aircraft for special Viet Nam missions. Like the P-2, the S-2 is obsolete, but the S-2 does not have a successor in inventory or production. Available S-2 inventories have not been investigated. Compared to the P-2, the S-2 has smaller payload, less endurance, lower costs and better low-altitude performance. Nevertheless, the P-2 is now considered to outweigh the S-2 as a candidate. More evidence is required.

E. Early Warning. The E-1B has much the same characteristics, in terms of HARR, as the P-2 and S-2. The E-1B also has avionics which may abet the HARR mission and facilitate multi-mission operations in Viet Nam. Short-comings may be in the areas of availability, theater logistics, command channels, etc.

T. Trainer. While a number of candidates were rejected because of on-station characteristics and costs, nine remained. The T-37B and T-30A appear to be primary candidates for Viet Nam and Quick Fix. This type aircraft must be subjected further to the same sort of selection/rejection criteria already applied. One possibility is to select a large, slow, inexpensive model and subject both models to cost/effectiveness analyses.

C. Cargo. Larger models were rejected because of excessive capacity and cost, and some of the remaining 9 candidates are marginal for this reason. The C-123B is in substantial use in Viet Nam, and the C-47E and C-121G appear likely candidates.

CV. Cargo. The CV-2B is a special candidate because of its availability, logistics support, experience in Viet Nam, etc. This aircraft is one transferred from Army to Air Force, per the April 1966 agreement. Investigation of the impact of this transfer on the CV-2B's HARR candidacy is desirable.

U Utility. A few aircraft of this type appear marginal because of on-station limitations, cost and limited availability, but none were rejected. The U-1A and U-6A are favored because of their present use in Viet Nam. More specific criteria are needed for subsequent selection/rejection. Because of the apparently good candidacy of this aircraft type, a preferability ranking may be needed, rather than suitability exclusions. Relative ranking versus observation aircraft also seems desirable.

UH Utility Helicopter. The UH-1's prevalence in Viet Nam makes it a primary candidate. All versions (including the earlier UH-1B and the new 2-engine model) must be investigated. The UH-2A is less available, probably relatively costly, and possibly not divertible from other missions. The UH-1 is, in terms of HARR, in competition with Utility Fixed Wing aircraft.

OH Observation Helicopter. There are three good candidates to be reduced to one by some criteria not yet derived or applied. Payload and environmental limitations are expected to rule this type out in favor of Fixed Wing Observation aircraft or Utility Helicopters.

CH Cargo Helicopter. The CH-34 (also designated UH-34) is a primary candidate used extensively over Viet Nam from land and carrier basing by both Navy and Marine Corps. The CH-37 and CH-21A appear to be poorer cost/effectiveness candidates. Unless the HARR payload increases and platform maneuverability becomes a premium factor, the CH-34 may be rejected through subsequent analysis.

4.5.4 Cost-Effective Analysis. As is customary in a cost-effectiveness analysis, the effort was divided into two major areas--that pertaining to HARR operational effectiveness and remote area suitability, and that pertaining to cost. Not in all cases were these areas kept separate. This was because logistic and base support costs were to a large degree dependent on a platform's present status in the U.S. inventory in South Viet Nam and the experience or lack of experience with the candidate in the Pacific theater.

4.5.4.1 Effectiveness Model. By considering the communications requirements discussed in Section 2, and by material found in the Remote Area Conflict Information Center (RACIC) Library, platform mission requirements were specified. These requirements were as follows:

a. Overcome Foliage and Terrain. The platform height was required to meet minimum altitude limits that would overcome both the foliage and terrain problems. If platform altitudes, such as the tethered balloon or treetop net, did not meet this minimum altitude requirement, either their height had to be increased or else the altitude deficiency would have to be made up by the height of the ground at which the platform was tethered or supported. Also, when terrain masking avoidance became a problem, either the extra penalty in payload, special equipment, and on-station endurance costs had to be accepted or the burden had to be shared by special ground-to-air-to-air-to-ground provisions.

b. Avoid Mutual Frequency Interference. As expressed elsewhere in this document, a critical platform requirement was that it carry the additional payload or incorporate within its ground system the sophistication necessary to avoid mutual frequency interference. The AN/PRC-25 repeater range improvement figures shown in Section 3 (a flat earth range of 150 miles for an altitude of 19,650 feet for an allowable path loss of 140 db, or a ground distance of 50 miles for an equal path loss at a 1,775-foot altitude) showed that an altitude improvement payed off handsomely in range; however, mutual frequency interference was now inevitable.

c. Meet Tactical and Environmental Conditions. Among the critical parameters considered in the analysis were force deployment and environmental conditions. The required employment tactics are discussed in Section 2 of this document. As much as possible, these were the tactical deployment practice and environmental conditions as they now exist in South Viet Nam.

d. Remain Compatible with Operational Doctrine. Through conferences held with U.S. Army aircraft project managers at AVCOM in St. Louis, Missouri, it was learned that flight crew, ground support, and logistic supply were critical factors to be considered in the evaluation of military aircraft. Often, aircraft manuals present endurance curves that are true for the vehicle, but not for the flight crew, particularly when day-in, day-out, on-station missions are to be flown, such as are required by HARR. Also it was learned that particular care should be taken that the logistic and ground support requirements of a system should not exceed supply and maintenance adjustment limitations. As a consequence, if a platform already exists in the U.S./Viet Nam inventory, it would have a favorable advantage over one that was not; and when it was found that a candidate required unusually demanding repair, logistic or operational support (such as fuel), it was dropped from consideration.

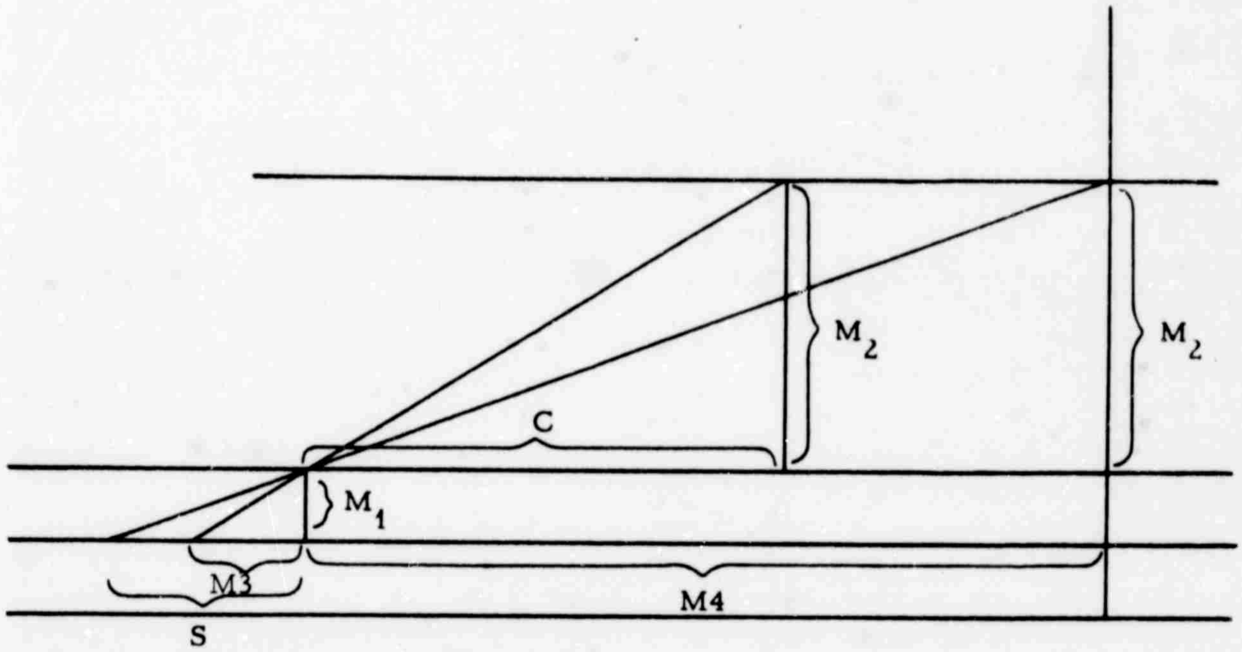
4.5.4.1.1 Environmental Considerations

a. Weather Analysis. For the application of both balloon and aircraft platforms, an understanding had to be established as to the influence of upper winds and surface weather on total operational availability. Upper air winds and surface weather information was obtained from the Environmental Technical Applications Center, Washington, D.C. Specific Viet Nam operational flying condition information was obtained from the AVCOM Army Aircraft Project Offices and specific surface weather percentages, according to South Viet Nam area distribution, from the AVCOM Foreign Intelligence Office. The environmental influences are treated later in the discussion of the cost-effectiveness curves.

b. Terrain Analysis. An important part of the effectiveness model was the amount of transmission coverage that could be counted on from an on-station platform. It was known that this varied with the altitude of the platform and the terrain of the area being covered. Since the South Viet Nam topography varied from the rough mountainous terrain in the north to the lowlands of the south, it was imperative that a terrain analysis be made. Such an analysis was not found to exist which met HARR requirements, and a means had to be obtained that would give the terrain slope results that fell within HARR platform positional limits. These limits were broad, and the terrain analysis was not done in precise detail.

The methodology employed was to obtain a large topographic chart of South Viet Nam. The scale used was 1:1,000,000; the chart was then divided up into sections representing ARVN Corps I and II over the northern half and the ARVN Corps III and IV over the southern half. Cross sections were taken over each position of an area that indicated topographic change. The spacing of the contour lines gave the degree of slope.

Shadow Zones were computed according to the geometry and equations shown in Figure 4-7. A section of the II Corps area which represents a typical terrain analysis is shown in Figure 4-8. Location of the shadow zones was determined by examining every location that appeared likely. The only exception was the case of the gullies whose banks might have been considerably steeper than the immediately surrounding terrain. As an example, it is probable that a considerable portion of the area around Plei Girao Kup in the southeastern part (in Figure 4-8) is in shadows.



M_1 = Alititude difference in terrain

M_2 = Height of platform above highest terrain feature

M_3 = Contour spacing

M_4 = Distance, platform to highest terrain feature

K = Intermediate factor; $K = \frac{M_2}{M_1}$

C = Intermediate factor; $C = (M_3)K$; If $C = M_4$ there is no shadow

S = Length of shadow; $S = {}^{(M_4)}/_{(K)}$; Measured from highest terrain feature at level of M_3.

$$K = \frac{M_2}{M_1}$$

$$C = (M_3)(K)$$

$$S = {}^{(M_4)}/_{(K)}$$

Figure 4-7. Shadow Geometry

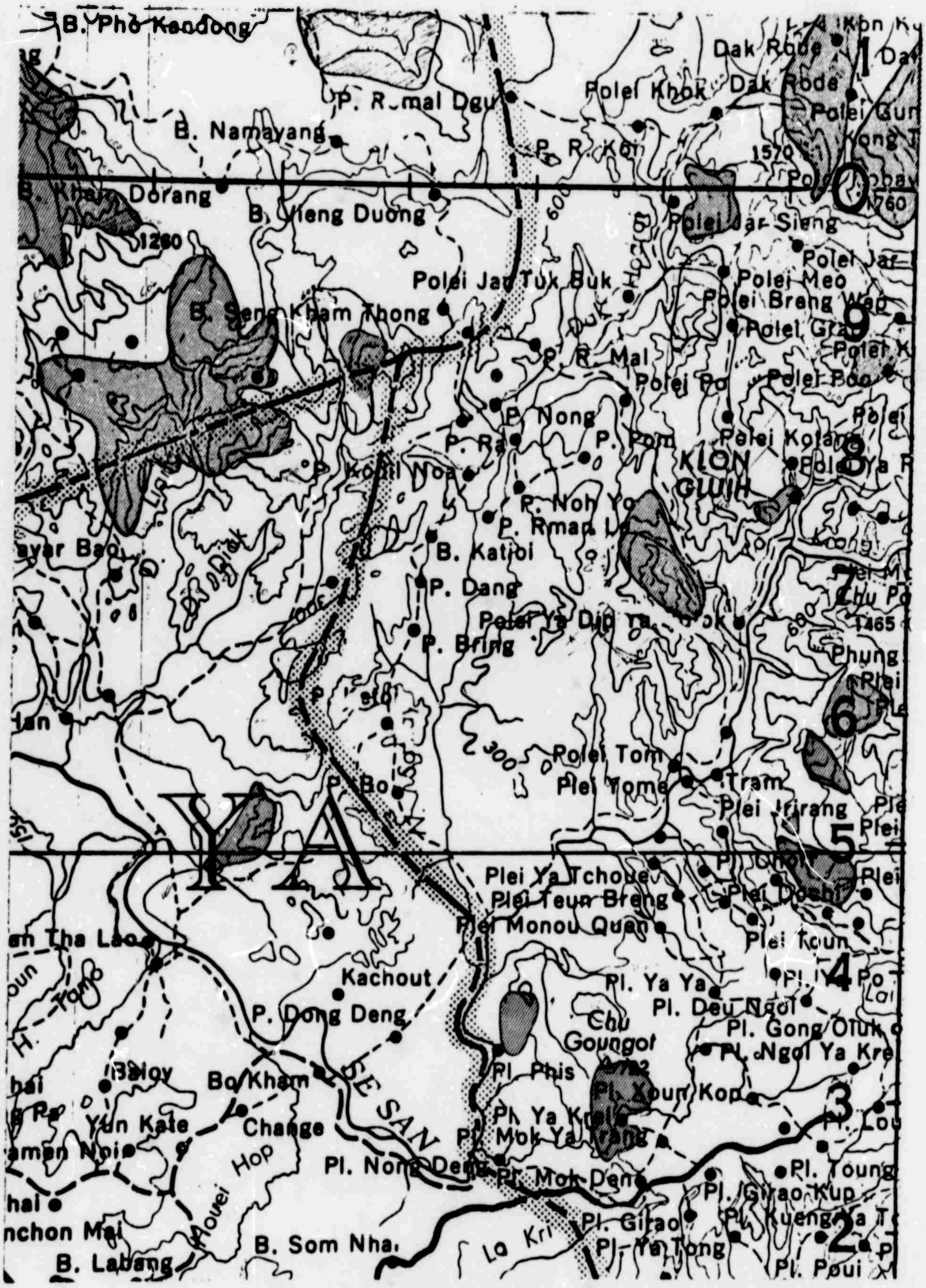


Figure 4-8. Typical Terrain Analysis - Vietnam
(Elevation in feet)

The extent of the platform station was determined graphically as the intersection of a plane at 20, 000 feet, with extensions of the slope of the terrain. The general location was first selected by inspection. For the purpose of calculating station extent, ambient terrain slope was doubled. Thus the station envelope, represented by the hatched, pear-shaped area near the "KLON GLUIH" letters, is appropriate for a 10, 000-foot platform, if ambient slopes are considered adequate, and for a 20, 000-foot platform, if twice the ambient slopes is felt to be more realistic. The approximate center of the station area was used for locating and determining the extent of the shadow. For this rather mountainous section of the II Corps area the shadow zones were estimated to take up less than 5 percent of the total territory of Figure 4-8.

c. Area of Coverage Cones. The two considerations of terrain masking avoidance and foliage penetration were applied to obtain needed platform "cones of coverage." Considering the propagation take-off angle requirements discussed in Section 3, a limiting horizontal angle of 10° was obtained. Figure 4-9 illustrates this foliage penetration angle. When terrain was not the limiting cone of coverage factor, the 10° angle was used.

Figure 4-9 also illustrates the manner in which the terrain-limited cone of coverage was estimated. The maximum slope of the terrain was used which was greater than the 10° foliage limiting angle and which sustained a "line-of-sight" angle that reached to the platform's position at the apex of the coverage cone. The useful area was determined by the intersection of the cone of coverage with the topography, or else by the horizon which made up the 10° foliage-limiting angle.

As might be expected, the area covered by an on-station platform, particularly in rugged terrain, would be quite irregular. This irregularity is illustrated in Figure 4-10. This terrain/relay coverage interface is discussed in the paragraph that follows.

Interface Between Relay and Terrain. With respect to a relay-carrying airborne platform, three major physical factors determine its effectiveness. These are:

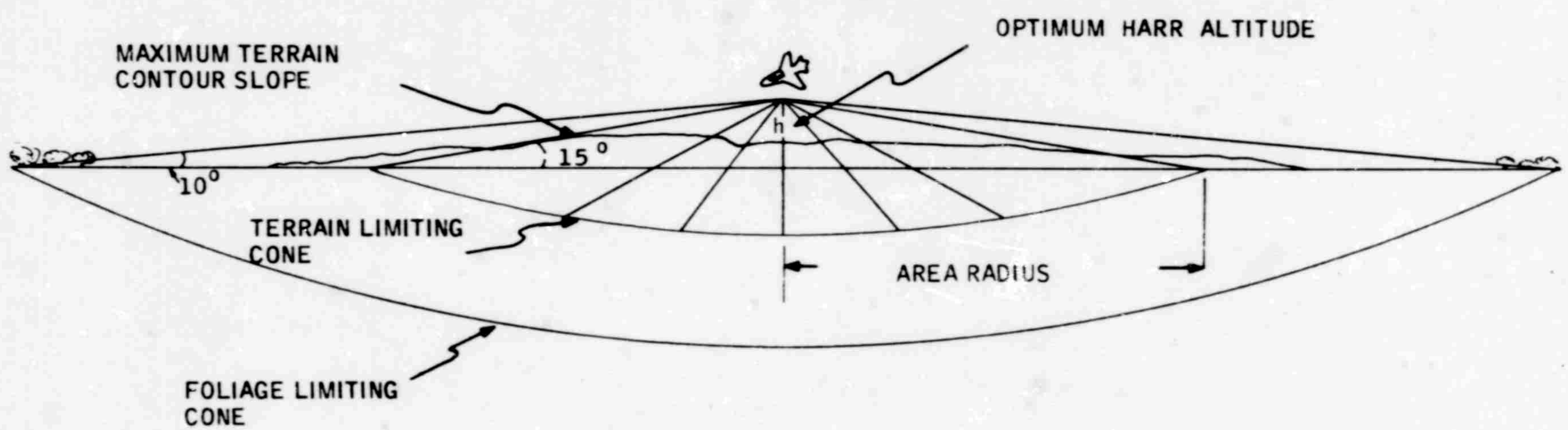
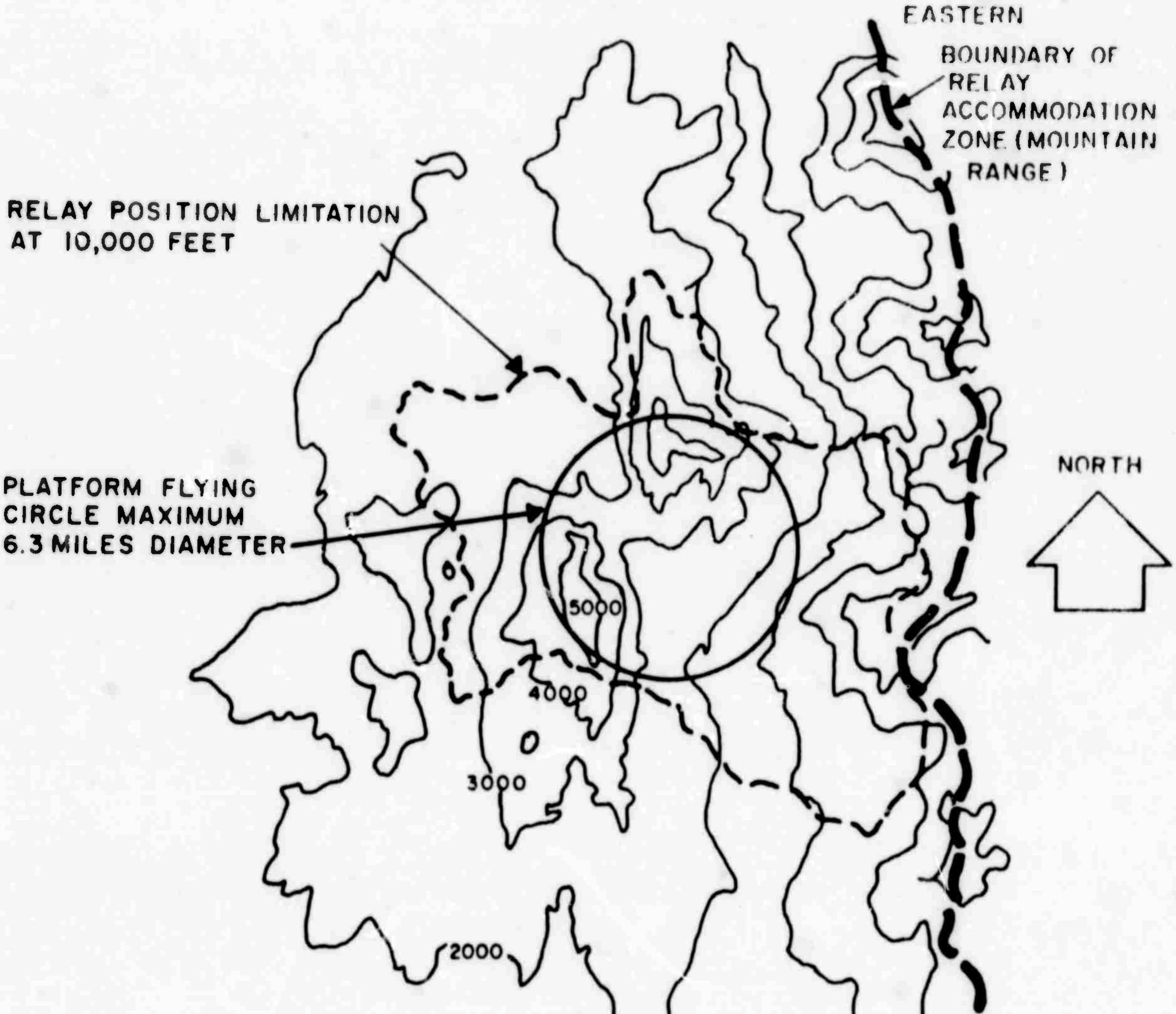


Figure 4-9. Platform Terrain and Foliage Limiting Cones



TOPOGRAPHY SAMPLE OF SOUTH VIETNAM TERRAIN

SCALE 1" = 4 MILES

Elevation in feet

NOTE:

TOTAL ZONE SERVICED BY THIS RELAY APPROXIMATELY 30 MILES SQUARE

Figure 4-10. Irregular Area of Coverage Due to Rough Terrain

Position	The ability to hold the relay within defined space limits, plus getting it there and back to base.
Environment	With its normal variations; weather sometimes becomes untenable for certain platforms to achieve or hold position.
Configuration	Effect of platform on relay and antenna design.

This discussion deals only with the relay position factor, and advances the idea for terrain definition in terms of platform position on-station.

For purposes of analysis, platform position may be defined as an area over terrain at an arbitrarily selected constant altitude. The limits of this area may be defined by a value of computed signal strength representing an acceptable threshold between receiver sensitivity and voice transmission from a standard man-pack radio at any point on the ground. The transmitted signal will be influenced by indigenous vegetation and roughness of terrain plus normal attenuation for distance. A signal strength contour may then be determined at the selected altitude which describes an irregular envelop within which the input voltage at the relay receiving antenna will exceed the threshold signal strength. For simplicity, the irregular contour should have inscribed within it a circle which defines the relay position limits to be maintained by the platform. An example is given in Figure 4-10.

For a moving platform whose optimum performance altitude differs from the altitude selected to define the terrain, a suitable value for relay position factor may be computed based on free space attenuation and threshold signal strength patterns for higher (and possibly lower) altitudes. Higher altitudes should produce larger circular "on-station" areas over mountainous terrain as line-of-sight angles are relieved.

As shown in Figure 4-10 the dashed-line enclosed area is the guaranteed coverage an aircraft, flying in the 6.3-mile-diameter circular pattern, can obtain when holding a 10,000-foot altitude. The coverage is maintained despite the aircraft's position on the circumference.

d. Coverage Requirements. The area chosen for the first coverage investigation was that of the ARVN II Corps. This, as has been mentioned before, was a fairly rugged terrain characterized by considerable tropical foliage. An O-1E Bird Dog aircraft was chosen as the platform in this analysis. To obtain adequate coverage of this area where some peaks reached nearly to 9,000 feet, it was estimated that the Bird Dog should fly at a constant altitude of 13,000 feet. Figure 4-11 shows the areas of coverage which would have to be provided in order for complete II Corps blanketing by the required 24 simultaneous station-keeping Bird Dog aircraft.

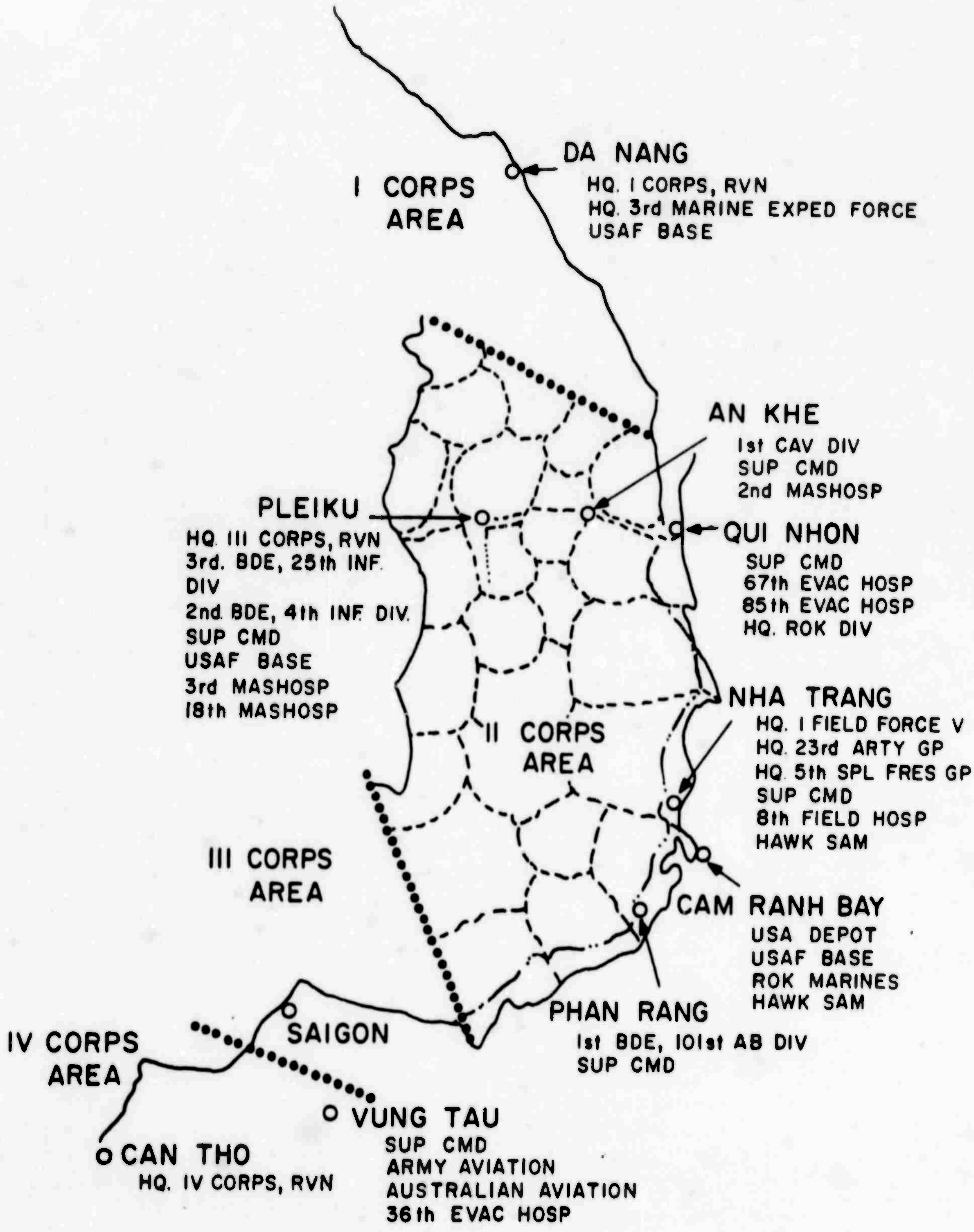


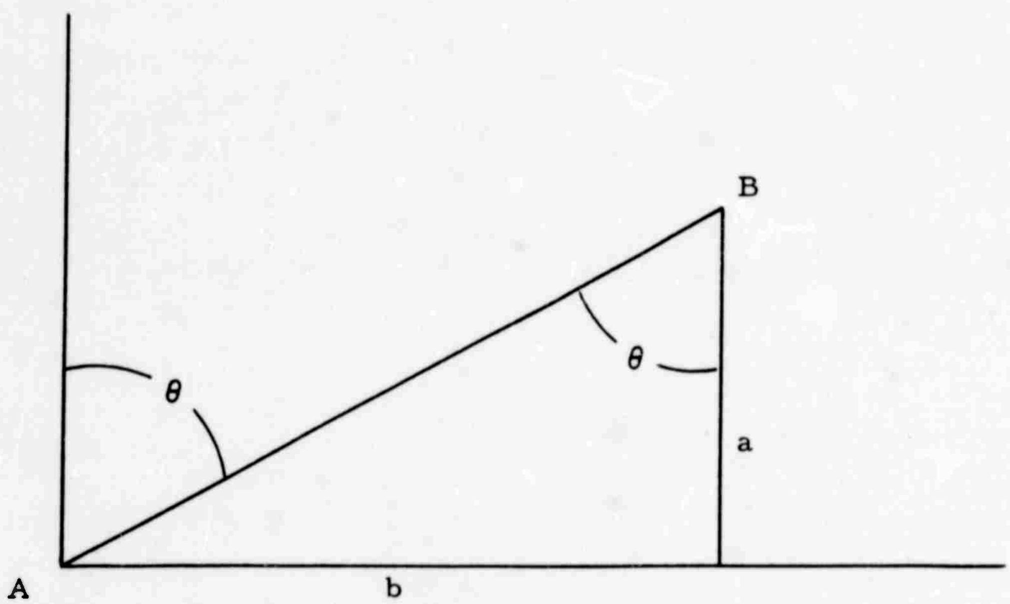
Figure 4-11. Area of Coverage for II Corps by Required 24 On-Station O1-E Aircraft

4.5.4.1.2 Tactical Analysis. The tactical doctrine applied in the HARR platform effectiveness modeling is described in some length in Section 2. This doctrine, as presented in Section 2, was used as the basis for determining platform and communication channel allotment and in building platform tactical employment models.

A. Platform Placement and Communication Channel Allocation

1. Under the simplifying assumptions that for (a) the propagation is a straight line, then (b), the portion of the earth of interest, can, with acceptable accuracy, be treated as a plane.

In this Section, platform altitudes are considered only on the basis of communications requirements and ignore minimum altitude problems of ground fire, etc. The essential elements of the platform placement problem can be represented in the following sketch.



The line AB represents an element of the cone within which communications are confined by terrain, foliage or other mechanism, about a station on the ground at A. That cone can be completely defined by the angle θ where:

$$\theta = \tan^{-1} \frac{b}{a} = \tan^{-1} \frac{1}{\text{terrain slope}}$$

A platform at B is theoretically within the line-of-sight (LOS) of any ground station along b.

In order for a platform at B to cover an area of radius R on the ground, the platform altitude of h must be determined by:

$$h = R \tan \theta = \frac{Rb}{a}$$

2. Figure 4-12 depicts (at distorted scale) the constraints on line-of-sight thus far considered as they apply to discussions which follow.

The line labeled "35%" represents the constraint which will be assumed to apply in rough terrain. It corresponds to an angle of about 70° from the vertical and is at a slope approximately double (when expressed in %) of the slopes which could be measured on the 1:1,000,000 scale charts available. Although the 35% slope may adequately describe the general terrain, there are undoubtedly local conditions which result in much more severe constraints. Those conditions exist at the bottoms of steep-sided gullies and even behind peaks where the slope may be nearly vertical.

The line labeled "80°" represents the constraint which will be assumed for flat terrain and reflects the best currently available estimate of the effects of foliage.

The line labeled "Flat Earth" represents the horizon constraint applicable over water. As long as airborne platforms are above intervening terrain, line-of-sight contact between platforms are governed by flat earth geometry.

The dotted line from 1 to 2 in Figure 4-12 depicts two airborne stations at 5,000 feet altitude and 25 nautical miles apart. The dotted line from 1 to 3 depicts two airborne stations separated by 25 miles horizontally and 5000 feet vertically with the lower station at 5,000 feet. Stations 1 and 3 are within line-of-sight of each other unless intervening terrain interferes, such as, for example, a mountain of altitude greater than 7,5000 feet at the point midway between the stations.

The tolerable intervening terrain altitude is expressed by:

$$h = h_1 + \frac{d}{S}(h_2 - h_1)$$

where:

- h is the height of terrain which will just intercept LOS
- h_1 is the altitude of the lower platform
- h_2 is the altitude of the higher platform
- S is the horizontal platform spacing

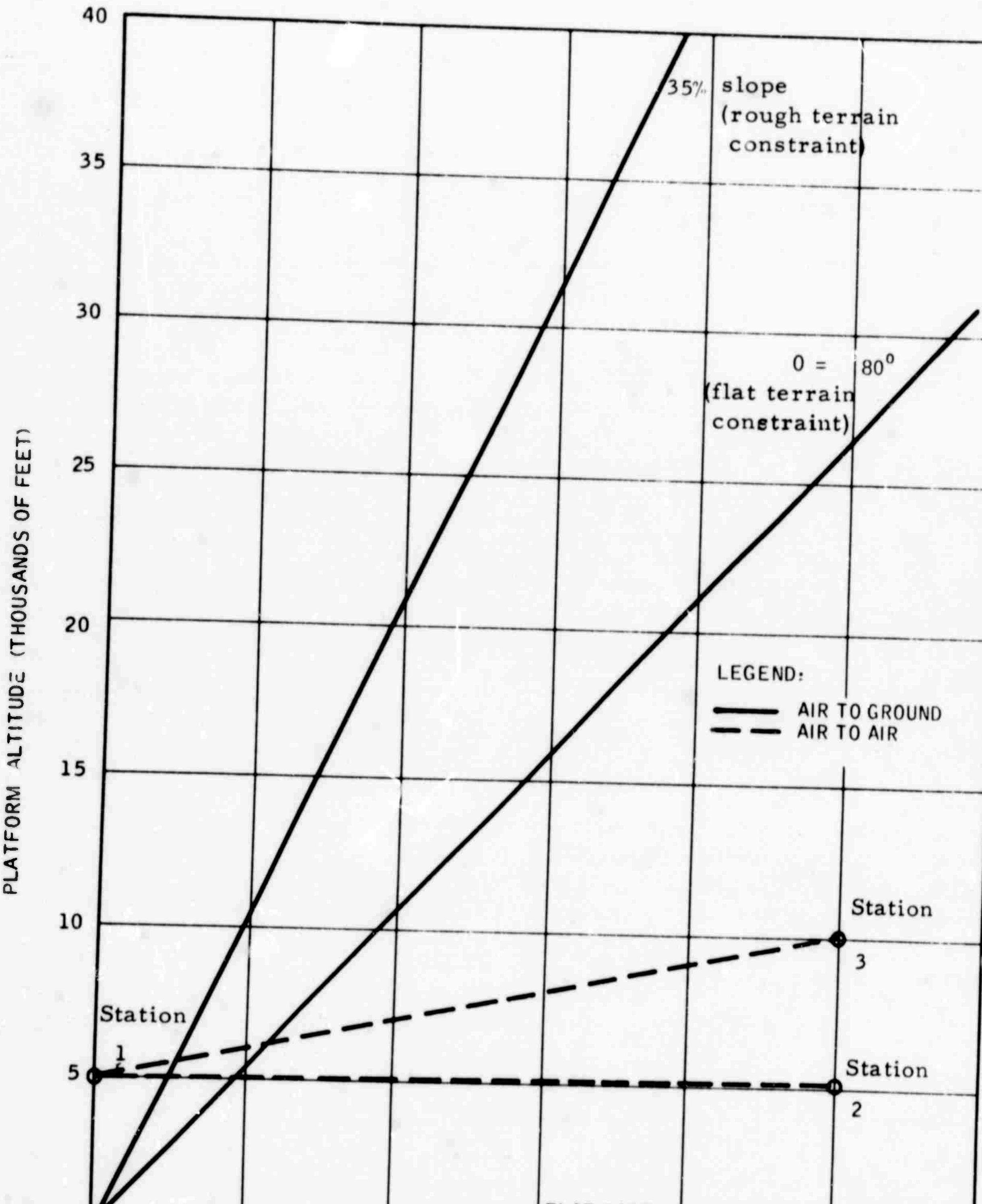


Figure 4-12. Communication Envelopes

d is the horizontal distance from the lower platform to the terrain feature being considered.

If both platforms are at an altitude which exceeds by 200 feet the height of any intervening terrain, they will be in LOS of each other.

The error in assuming a plane geometry treatment is on the order of 60 feet over the 25-mile interval. That error is ignored as insignificant in comparison to other uncertainties such as, for example, the accuracy with which the platforms will maintain altitude.

It must be noted at this point that to ensure the desired coverage under any constraint, the platform altitude must be measured from the highest terrain located in the area to be covered.

3. Figure 4-13 depicts the deployment and the elements of a battalion which are assumed in the discussions which follow. This deployment may be considered as something of a "worst case" in that an infantry battalion will rarely present a disposition of forces more widely separated.

4. Figures 4-14 and 4-15 illustrate application of the previously described concepts of coverage to the battalion deployment shown in Figure 4-13. Figures 4-14 and 4-15 depict the inverted cones of coverage in vertical cross section from various platform altitudes and locations when line-of-sight is defined by 80° and 35% constraints, respectively.

Figures 4-14 and 4-15 illustrate two factors which are generally appropriate:

(a) The minimum acceptable platform altitude is a function of:

(1) the dimensions of the area to be covered

(2) the envelope within which propagation is constrained.

There is also a maximum altitude above which it may be profitable to consider a different deployment of platforms. This is illustrated by points 1 and 2 in Figure 4-14 for example. A platform at 1 can theoretically bridge the communications gap between the platoon leader and company commander. If platform altitude is increased to the level of 2, the capability exists of covering all platoons of a company as well as the company commander. If the platform can carry a sufficient number of relays, it is feasible that it service the entire company.

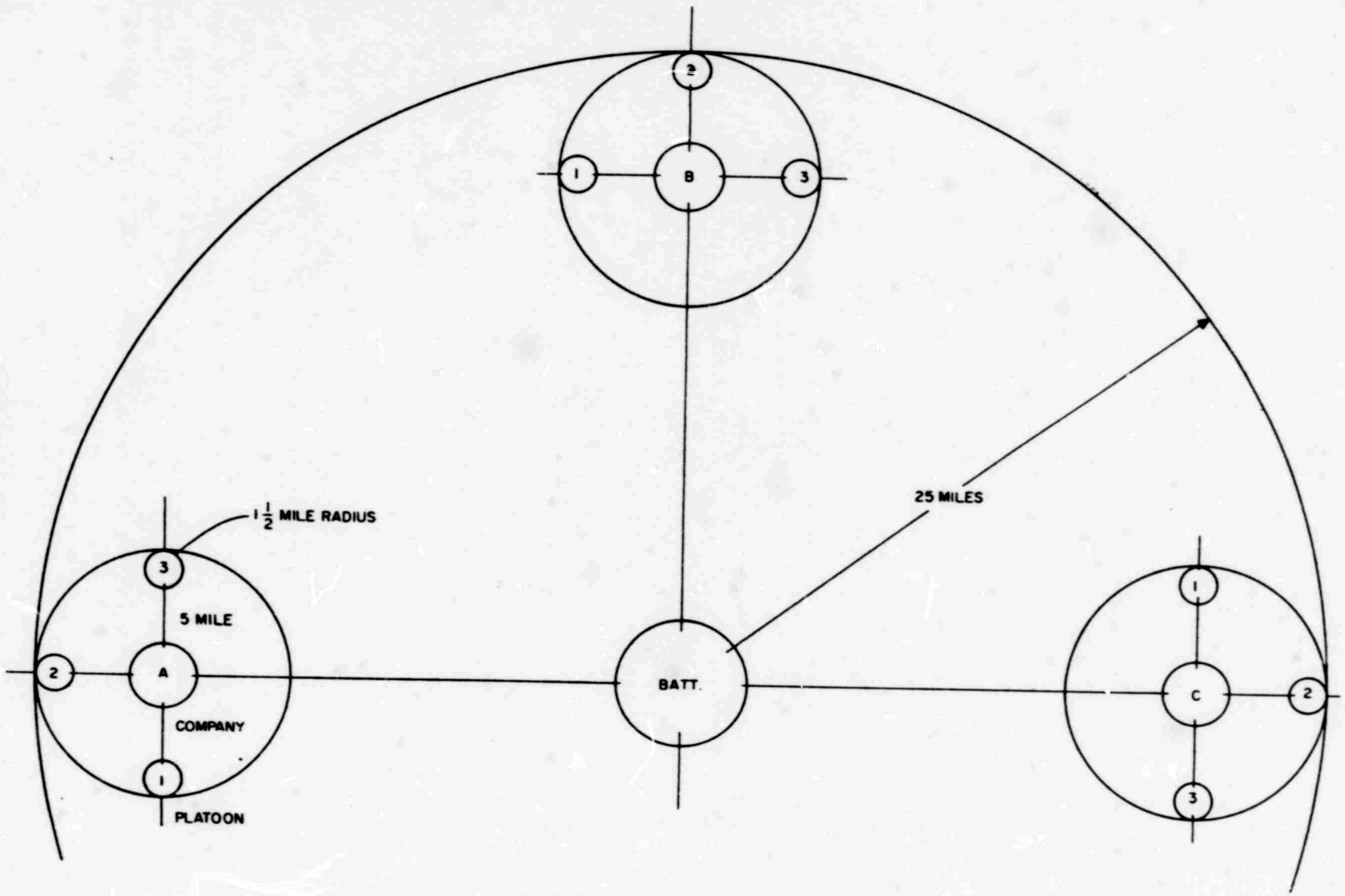


Figure 4-13. Assumed Battalion Tactical Deployment

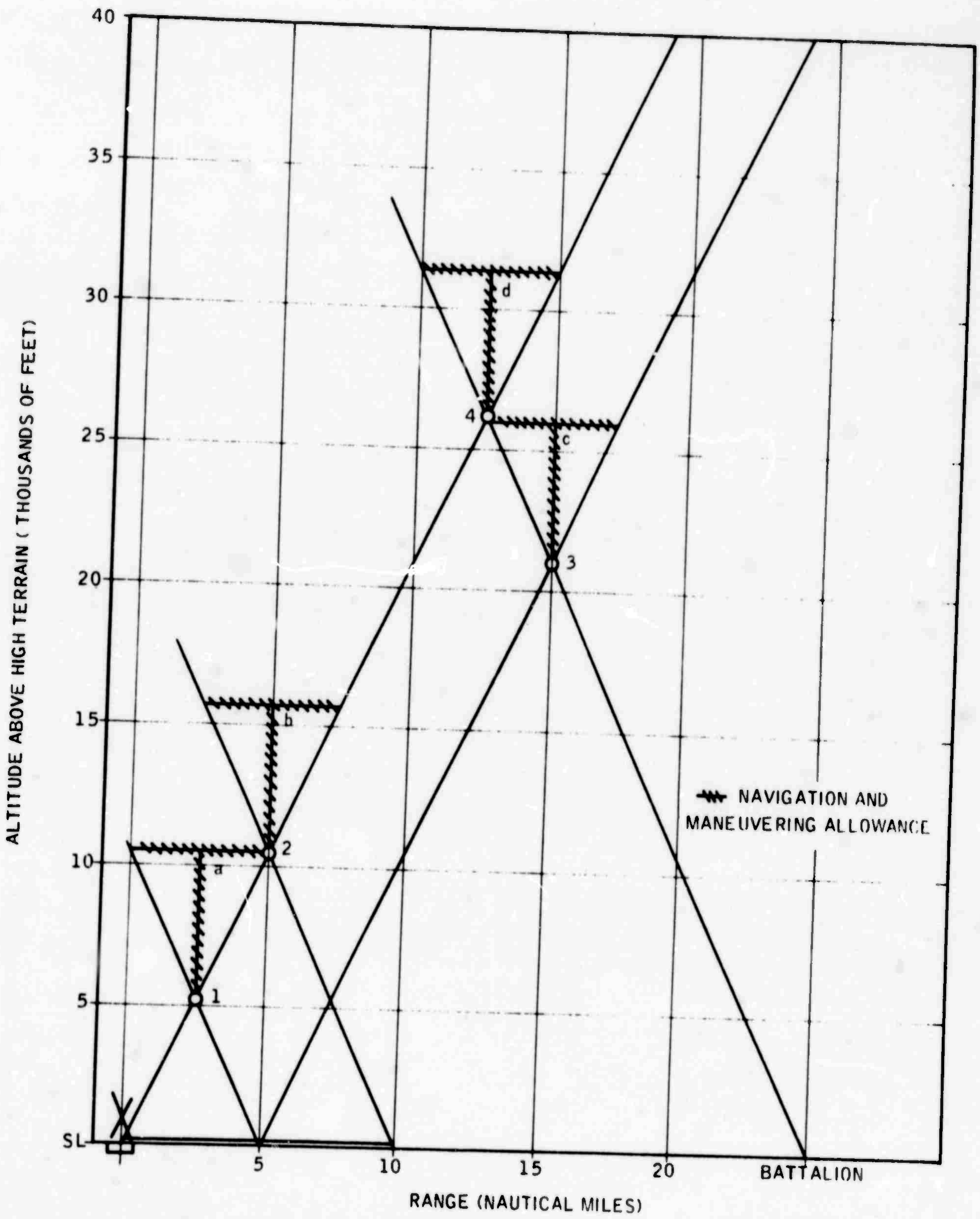


Figure 4-14. Platform Placement in 80° Constraint

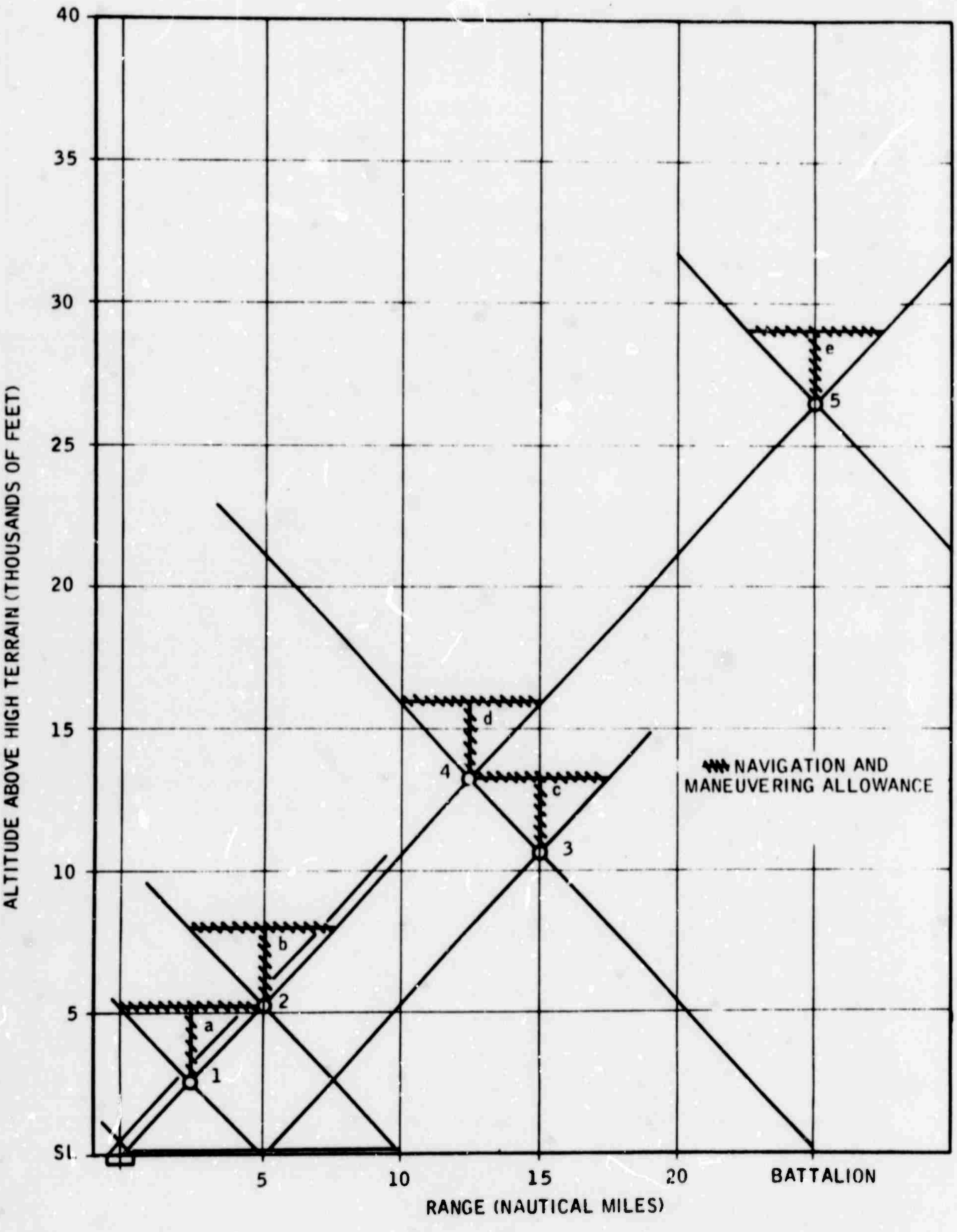


Figure 4-15. Platform Placement in 35% Terrain

(b) The precise positions, such as 1 and 2 in Figure 4-14, cannot be maintained even by tethered balloons. Fixed-wing aircraft must maneuver to stay airborne, and the "brute force" hover of rotary-wing craft reduces endurance. Furthermore, navigational inaccuracies are unavoidable. Thus some allowance must be made for maneuvering and navigational uncertainty. Stations shown in Figures 4-14 and 4-15 labeled a, b, etc., corresponding to and above stations 1, 2, etc., represent the increase in station altitude required to allow for a cumulative 2-1/2-mile error, or to allow a 5-mile diameter maneuvering space. As a maneuvering space, such a circle corresponds roughly to the room required to fly a race track holding pattern with 2-minute legs. Eight hours of that maneuver may be more than a pilot can endure.

It is assumed for the purpose of this report that "over coverage" is not desired. For example, the space between battalion and company headquarters may be occupied by transient traffic but the requirement for relay of vital communications does not concern that traffic. Thus, a platform at such an altitude as to provide coverage not only for the vital areas but for some space outside is providing "over coverage." Some "over coverage" is unavoidable, indeed necessary, but not necessarily desirable. "Over coverage" may also be considered to exist when a ground station has direct access to more than one platform, since relay between platforms is generally unimpeded by the mechanisms which hamper surface communications.

B. Tactical Employment Models

The tactical models described in the following paragraphs produce estimates of the number of platforms required as a function of platform altitude and assumed situation. Table 4-4 lists the results for the following tactical situations, each of which is described in more detail later:

Situation 1, in which the objective is to "cover" South Viet Nam completely. Numbers of platforms required are generally untenable in terms of manned aircraft.

Situation 2, in which the infantry company with a radius of five miles is the smallest tactical unit considered. Platform altitude must be great enough to ensure coverage of the five-mile radius circle. Tabulated numbers represent the number of platforms required per infantry battalion.

Situation 3, in which it is necessary to ensure continuity of communications from platoon through battalion headquarters. Numbers listed in Table 4-4 are the number of platforms required on station per battalion as a function of platform altitude.

Table 4-4. Platforms Required for Given Altitudes/Situations

Platform Altitude (in thousands of feet)	No. of Platforms Required: Situation 1, ARVN CORPS I II	Situation 1, ARVN CORPS III IV	Situation 2, ARVN CORPS I II	Situation 2, ARVN CORPS III IV	Situation 3, ARVN CORPS I II	Situation 3, ARVN CORPS III IV
0.1		23			16	16
0.5		6			16	16
1.0		4			16	16
2.0		3			16	16
3.0	5,470	2			16	10
4.0	3,170	2			16	7
5.0	1,890	2			16	7
6.0	1,310	2		4	10	4
7.0	1,000	1		4	7	4
8.0	755	1		4	7	4
9.0	585	1		4	7	4
10.0	471	1		4	7	4
12.0	333	1	4	4	4	4
14.0	241	1	4	3	4	3
16.0	188	1	4	3	4	3
18.0	146	1	4	3	4	3
20.0	120	1	4	2	4	2
25.0	75	1	4	2	4	2
30.0	55	1	3	1	3	1
35.0	39	1	3	1	3	1
40.0	30	1	2	1	2	1
45.0	24	1	2	1	2	1
50.0	19	1	2	1	2	1
60.0	14	1	1	1	1	1

1. Application. This model produces as a result, the number of platforms required on station at a given time to meet various communications requirements of an infantry battalion. Numbers listed in Table 4-11 may be multiplied by the on-station flight hours to obtain operating costs.

2. Assumptions. The results of the investigation at this stage reflect the assumptions listed below:

(a) Effects of Terrain and Foliage. South Viet Nam was divided into two regions described generally as "mountainous" and "flat." These regions correspond fairly closely to ARVN Corps Zones I and II for mountainous terrain, and Zones III and IV for flat terrain. It was assumed that terrain masking was the principal impediment in the mountainous region. Communications were restricted to a zone above terrain with a "worst average" slope of 35%. In flat terrain, two conditions were assumed. In Situations 1, line-of-sight capability with no interference was assumed. In Situations 2 and 3, communications were assumed restricted by the terrain at a slope of 35% in Zones I and II and by foliage to within a 160^{o} cone in Zones III and IV.

(b) Relay Capability and Interference. These two factors were ignored as problems in this phase.

(c) Effective Radio Range. Extremely high altitude platforms provide line-of-sight coverage to ranges that may exceed the capability of the transceivers under consideration. The effect of incorporating the restrictions inposed by free-space attenuation will be to reduce the radius of coverage. For the purposes of this study effort, the effect has been ignored.

4.5.4.2 HARR Platform Costing. The costing was divided according to whether the candidate was an aircraft or a special platform. In turn, the aircraft costs were divided according to whether the vehicle was manned or unmanned.

4.5.4.2.1 Costs for Manned Military Aircraft

A. Cost Factors

Several factors contribute to the cost of providing a manned military aircraft such as a HARR platform. These factors are:

1. Cost of the aircraft.
2. Cost to replace aircraft lost through attrition.
3. Cost of fuel and oil for flying.
4. Cost of replacement parts consumed in the maintenance process.
5. Cost of manpower required for maintenance.
6. Cost of a flight crew for the HARR mission.
7. Cost of personnel (not part of the HARR program) providing support for HARR operations.
8. Cost for the HARR "fair share" of base operating support.

Information on these costs is presented in Tables 4-5 and 4-7. Table 4-6 provides data on the requirements for military personnel to conduct and support HARR operations. Table 4-5 gives purchase and operating costs for the candidate aircraft. It lists each candidate and its cost, then gives the attrition rate (losses per flight hour), the attrition cost ($/FH), the cost for fuel oil ($/FH), the cost for replacement parts ($/FH), and the total direct operating cost ($/FH). The total is the sum of the costs for attrition, fuel and oil, and replacements parts.

Table 4-6 gives a breakdown of the military personnel requirements. It lists each candidate, its use rate (flight hours per month), and a particular crew requirement case. Case 1 of Table 4-6 requires the basic HARR flight crew. For this case, the relay repeater equipment will be operated by one of the basic crew. Case 2 requires the basic flight crew, plus a relay repeater operator. For this case, it is assumed that the relay repeater equipment consist of many channels which must be monitored and operated by an additional crew member. Case 3 requires the basic flight crew, plus a relay repeater operator, plus relief personnel. For this case, it is assumed that the flight mission will have a long duration (approximately twenty hours), and extra flight personnel are needed to provide relief during the mission. Following the listing of the particular case, the required number of personnel are provided. The requirement is broken down into the officers and enlisted men needed for the flight crew, maintenance operation, and support.

Table 4-7 gives military personnel and base operating support costs for the candidates. The military personnel costs ($ per month) are listed as calculated from multiplying the personnel requirement by the personnel rate. Thus, for the O-1E which has a requirement for 4.6 officers and 7 enlisted men (for a rate of $1,000 per month per officer and $150 per month per enlisted man), the military personnel costs are $4,600 and $1,050, per month, respectively, for officers and enlisted men. These costs are added and divided by

Table 4-5. Purchase and Operating Costs

AIRCRAFT	COST	DIRECT OPERATING COST				
		Attrition		Fuel & Oil	Replacement Parts	Total
		Losses/FH	$/FH	$/FH	$/FH	$/FH
O-1E	$19,000	$15x10^{-5}$	$2.85	$2.00	$ 5.18	$ 10.03
U-1A	122,000	$13x10^{-5}$	15.87	4.09	4.53	24.49
U-6A	98,000	$13x10^{-5}$	12.75	3.20	8.49	24.44
U-8D	114,000	$13x10^{-5}$	14.82	5.06	7.52	27.40
CV-2	725,000	$13x10^{-5}$	94.25	21.41	69.37	185.03
C-47	300,000	$13x10^{-5}$	39.00	17.00	21.00	77.00
C-123	673,000	$13x10^{-5}$	86.81	38.00	36.00	160.81
OH-13	55,000	$44x10^{-5}$	24.20	2.83	11.64	38.67
UH-1D	247,000	$31x10^{-5}$	76.50	7.90	34.52	118.92

NOTE: Fuel and Oil Cost is for Normal Cruise.

Table 4-6. Personnel Requirements

Aircraft	Use FH/MO	Case	Personnel Flight		Requirements Maintenance		Breakdown Support	
			Off.	Enl.	Off.	Enl.	Off.	Enl.
O-1E	100	1	4	0	0	5	.6	2
U-1A	100	1 2	4 4	0 2	0 0	7 7	.6 .6	3 4
U-6A	100	1 2	4 4	0 2	0 0	9 9	.6 .6	4 5
U-8	100	1 2	4 4	0 2	0 0	9 9	.6 .6	4 5
CV-2	100	2	4	2	0	20	.6	10
C-47	100	2 3	4 6	4 6	0 0	9 9	.5 .6	4 5
C-123	100	2	6	6	0	17	.6	7
OH-13	50	1	2	0	0	5	.5	3
UH-1	50	1 2	2 2	0 1	0 0	7 7	.5 .5	4 4

CASE 1 A special relay repeater operator not required.
CASE 2 A special relay repeater operator is required.
CASE 3 A special relay repeater operator is required, and relief personnel are needed do to long duration flights.

Table 4-7. Cost of Military Personnel & Base Operations Support

Aircraft	Use	Case	Mil. Pers. Cost $/Mo.		Mil. Pers. Cost $/FH	B. O. S. Cost $/FH
			Off.	Enl.		
O-1E	100	1	$4,600	$1,050	$56.50	$56.50
V-1A	100	1	$4,600	$1,500	$61.00	$61.00
		2	$4,600	$1,950	$65.50	$65.50
V-6A	100	1	$4,600	$1,950	$65.50	$65.50
		2	$4,600	$2,400	$70.00	$70.00
V-8	100	1	$4,600	$1,950	$65.50	$65.50
		2	$4,600	$2,400	$70.00	$70.00
CV-2	100	2	$4,600	$4,800	$94.00	$63.00
C-47	100	2	$4,500	$2,550	$70.50	$47.00
		3	$6,600	$3,000	$96.00	$64.00
C-123	100	2	$6,600	$4,500	$111.00	$74.00
OH-13	50	1	$2,500	$1,200	$74.00	$74.00
					$83.00	$83.00
UH-1	50	1	$2,500	$1,650	$86.00	$86.00
		2	$2,500	$1,800		

Case 1, 2, & 3 are the same as for Table 4-6

Personnel rates are: $1000.00 per Officer per month
$150.00 per Enlisted per month

the flight hours per month (100 for O-1E) to give the military personnel costs per flight hour ($56.50 for the O-1E). The base operating cost is determined from a general relationship between the cost of military personnel and base operating support. This relationship is that for the cargo transport candidates (C-47, C-123 and CV-2) the base operating support is equal to 67% of the military personnel cost, and for the other candidates the base operating support cost is the same as the military personnel cost.

B. Basis for Cost Information (Table 4-5)

1. Aircraft Cost. The cost of the OH-13, UH-1D, U-6A, U-8D, CV-2B, U-1A, and O-1E are the values listed for flyaway cost in Section II of Chapter 4 of FM 101-20, rounded off to the nearest $1,000. The cost of the C-123 was obtained from personnel at Northrop Norair, and the cost of the C-47 is an estimate.

2. Aircraft Loss Rate (Losses per Flight Hour). The numbers of losses per flight hour for the CV-2, U-1A, U-8, UH-1, U-6, OH-13 and O-1E are the values listed for wartime MOB inactive or non-combat in Section III of Chapter 1 of FM 101-20, rounded off to two significant figures. The values for the C-47 and C-123 are assumed to be the same as for the CV-2.

3. Fuel and Oil (Dollars per Flight Hour). The costs for fuel and oil used per flight hour are taken from Section I of Chapter 4 of FM 101-20 for the U-1A, U-6A, U-8D, CV-2, OH-13 and UH-1; and for the O-1E, C-47 and C-123, they are taken from Table 4 of AFM 172-3.

4. Replacement Parts (Dollars per Flight Hour). The costs for replacement parts consumed in the maintenance process per flight hour are taken from Section I of Chapter 4, FM 101-20, for the O-1E, U-1A, U-6A, U-8D, CV-2, OH-13 and UH-1; and from Table 4 of AFM 172-3 for the C-47 and C-123.

C. Procedure for Determining Personnel Requirements (Table 4-6)

1. Determine Aircraft Use (Flight Hours per Month). The numbers for OH-13 and UH-1 are based on information contained in the April 1966 issue of United States Army Aviation Digest, which stated that the UH-1 helicopters are averaging over 50 flying hours per month. The numbers for the other aircraft are based on information in AFM 26-3H, 12 October 1966.

2. Determine Flight Personnel Requirements (Officers/Enlisted Men). The crews for the candidate aircraft are as follows: (These values arbitrarily selected)

O-1E	Case 1	2 officers	
U-1A	Case 1	2 officers	
U-1A	Case 2	2 officers	1 enlisted

U-6A	Same as U-1A		
U-8	Same as U-1A		
CV-2	Case 2	2 officers	2 enlisted
C-47	Case 2	2 officers	2 enlisted
C-47	Case 3	3 officers	3 enlisted
C-123	Case 2	3 officers	3 enlisted
OH-13	Case 1	2 officers	
UH-1	Case 1	2 officers	
UH-1	Case 2	2 officers	1 enlisted

Next, it is assumed that each flight personnel will fly 50 hours per month. Then one crew is required for the helicopters which fly 50 hours each month and two crews are required for the other aircraft which fly 100 hours per month.

3. Determine Maintenance Manpower (Enlisted Men). The number of maintenance men required is determined from the required MH/FH (maintenance man hours per aircraft flight hour). From FM 101-20, 25 March 1966, Section VIII, the direct productive maintenance man-hour requirements per flight hour (MH/FH) are:

U-1	5.77	MH/FH
U-6	7.79	MH/FH
U-8D	7.70	MH/FH
U-8F	7.01	MH/FH
O-1	4.29	MH/FH
CV-2	18.19	MH/FH
UH-1B	9.67	MH/FH
UH-1D	9.67	MH/FH
OH-13G	8.63	MH/FH
OH-13H	6.75	MH/FH
OH-13S	6.75	MH/FH

From AFM 26-3H, 12 October 1966, Table II, the maintenance manpower requirements are:

C-47	8 MH/FH	9 Men per aircraft for 100 FH per month
C-123	15 MH/FH	17 Men per aircraft for 100 FH per month
U-4	7 MH/FH	8 Men per aircraft for 100 FH per month
U-6	7 MH/FH	8 Men per aircraft for 100 FH per month
U-4	7 MH/FH	5 Men per aircraft for 50 FH per month
U-6	7 MH/FH	5 Men per aircraft for 50 FH per month

From this information, the following table is established:

Aircraft	Use	MH/FH	Maintenance Men
O-1E	100	4.29	5
U-1A	100	5.77	7
U-6A	100	7.79	9
U-8D/F	100	7.70/7.10	9
CV-2	100	18.19	20
UH-1B/D	50	9.67	7
OH-13H/S	50	6.75	5
C-47	100	8	9
C-123	100	15	17

4. <u>Determine Support Personnel Requirements (Officers/ Enlisted Men).</u> Requirements for support personnel are estimated based on published requirements on other aircraft. The following table is prepared from information presented in Table 1 of AFM 172-3, 31 March 1966.

	Program Personnel		Support Personnel	
Aircraft	Officers	Airmen	Officers	Airmen
F-100	3	21	.7	9.5
F-105	2.6	26	.6	11.5
B-57	3	15.6	.7	7
RB-66	8.4	30	1.8	13
F-4	4.3	30	.8	11.5
C-124	10	49	.6	9.5
C-130	6	32	.6	10

Values for the fighters and bombers are for General Purpose Forces and squadrons of 18 aircraft. Values for the cargo transports are for Airlift and Sealift Forces Industrial Fund and squadrons of 16 aircraft.

NOTE

Requirements listed
are per aircraft.

Based on the previous table, the following table is prepared to give estimates of the support personnel requirements:

Aircraft	Program Personnel Officers	Program Personnel Enlisted	Support Personnel Officers	Support Personnel Enlisted
O-1E	4	5	.6	2
U-1A	4	7	.6	3
	4	9	.6	4
U-6A	4	9	.6	4
	4	11	.6	5
U-8	4	9	.6	4
	4	11	.6	5
CV-2	4	24	.6	10
UH-1	2	7	.5	4
	2	8	.5	4
OH-13	2	5	.5	3
C-47	4	13	.5	4
	6	15	.6	5
C-123	6	23	.6	7

Requirements listed are per aircraft.

D. Cost Relationship for Share of Base Operating Support (Table 4-7). Costs for Base Operation Support are estimated, based on published requirements on other aircraft. The following table is prepared from information presented in Table 1 of AFM 172-3.

Aircraft	Military Personnel Cost $/aircraft/month	Share of B.O.S. $/aircraft/month
F-100	$11,400	$13,400
F-105	12,800	15,000
B-57	9,100	10,200
RB-66	20,200	21,200
F-4	16,200	18,900
C-124	27,900	18,500
C-130	18,600	12,600

For the cargo transports, the share of B.O.S. is approximately 67% of the Military Personnel cost. For the others, the share of B.O.S. is about 15% more than the Military Personnel cost. It is assumed that for the C-47, C-123 and CV-2, share of B.O.S. is 67%, as much as Military Personnel, and for the other aircraft, share of B.O.S. and Military Personnel costs are equal.

NOTE

> Share of B.O.S. for the other aircraft is assumed equal to Military Personnel rather than 15% more since B.O.S. of support aircraft would not be as costly as B.O.S. for tactical fighters and bombers.

4.5.4.2.2 Costs for Unmanned Military Aircraft HARR Platforms. The only drone candidate that survived to the cost-effectiveness "run-off" was the DASH helicopter.

The total flight hour on-station costs for the DASH helicopter when modified and equipped for the HARR mission are expected to be slightly above those given in Table 4-5 for the U-8D manned aircraft.

4.5.4.2.3 Costs for Special Platform Types

A. Tethered Balloon. The platform and tether line costs for a blimp-shaped tethered balloon platform are presented as follows:

Channels	Height	Airborne Weight	Ground Payload Weight	Platform Cost
2	2,000 ft.	48 pounds	150 pounds	$ 7,800
6	3,000 ft.	282 pounds	510 pounds	16,800
14	5,000 ft.	628 pounds	1,000 pounds	26,000
14	15,000 ft.	628 pounds	2,400 pounds	45,000

Under the assumption that a thethered balloon HARR platform would not be used during high winds, an attrition rate of .004 per flight hour has been estimated. It is also estimated that two-man teams working in eight-hour shifts will be required to fly and support a two-channel balloon system. This is increased to a three-man team for the six-channel system, a four-man team for the 14-channel system at 5,000 feet, and a five-man team for the 14-channel system at 15,000 feet. Ground support costs are based mostly on the 183-pound standard helium cylinders which must be supplied. Some estimates indicate that the balloons could remain aloft for only 48 hours; but with the improved material now available, an estimate equal to the life of the batteries is used.

Total single station and channel per flight hour costs are given below for the various suggested blimp configurations:

Channels	Attrition/ FH	Personnel/ FH	General Support/FH	Total System/FH	Total Channel/FH
2	$ 31.20	$ 5.05	$ 10.00	$ 45.25	$22.62
6	67.20	7.56	34.00	108.76	22.46
14 at 5,000 ft.	104.00	9.08	67.00	180.08	12.90
14 at 15,000 ft.	180.00	12.60	160.00	352.60	25.20

These costs do not include those for the repeater and its support.

B. Treetop Platform. The most expensive part of the treetop system will be the cost of the aircraft used to plant and recover the platform. The cost figures given are based on the use of a UH-1 helicopter which is estimated to be able to plant and recover 50 treetop platforms during its 50-hour monthly utilization. Some of the ground support will involve the handling and supply of the CO_2 bottles, but these costs are not considered to be high. The attrition rate, however, is estimated to be 10 times that of the tethered balloon. For a two-channel system not including repeater costs, the following estimates are given:

Channels	Attrition	Personnel	Deployment/ Recover	Total System	Total per Channel
2	$20/FH	$5.05/FH	$41.00/FH	$71.05/FH	$35.32

4.5.4.3 Cost-Effectiveness Modeling. Before the cost-effectiveness modeling was begun, it was decided that the major platform cost-effectiveness was to attain the greatest on-station time at minimum cost that was possible within HARR altitude, position keeping, and crew endurance constraints.

When the cost-effectiveness modeling was initially attempted, considerable care went into time and distance to home base considerations, turn around time, relief scheduling, number of backup aircraft needed, and many other operational factors. However, when all the flight hours required of a single aircraft for one month of HARR activity were totalled, almost invariably this total exceeded AVCOM established monthly flight hour limits specified for that aircraft. This brought the realization that the aircraft operational flight hour limit was the overriding factor, and that the modeling development had to be reinitiated with this consideration in view.

This second modeling development is described in the following paragraphs.

4.5.4.3.1 Cost-Effectiveness Model Design

A. Approach. The basic approach taken in designing the HARR cost-effectiveness model was to attack first those items of the total cost for which input data would most likely be obtainable. These appeared to be the costs associated with procurement and operation of the platform. It was assumed that platform suitability from an operational point of view would be evaluated in accordance with a tactical model, the development of which is proceeding separately. The cost-effectiveness model was intended to be applied in making a selection of a platform or a platform mix, from a set of operationally suitable platforms, on the basis of the cost of mounting and sustaining the effort during the greatest practical on-station time.

The model was designed to accept as inputs those cost items commonly available in terms of the parameters in which costs are commonly expressed. As an example, ground support costs are often stated in terms of the flight hours per aircraft-month. Accordingly, flight hours per aircraft-month was taken as a basic parameter.

Consideration of other costs, such as training, was deferred until a more firm estimate of the required effort was established.

B. Inputs

1. Flight hours per aircraft month: This is the basic parameter by which operating costs are computed.

2. Operating costs per flight hour: This is a function of the flight hours per aircraft month.

3. Support costs per flight hour: This is a function of flight hours per aircraft month.

4. Endurance and other platform performance characteristics: These characteristics are necessary in determining the number of platforms required, both at the operating base and in the system.

5. Failure and loss rates: These factors are necessary in determining the number of platforms required, both at the operating base and in the system.

6. An assumed tactical situation which defines the distances to be transited, on station times, and number of sites to be supported.

C. Unaccounted Items

1. Aborted Flights. If an abort rate is available or can be estimated, it may be applied to the number of aircraft required on the flight line. An aborted flight will most likely be replaced, with the result that additional flight line aircraft are required.

2. Inclement Weather. It is possible that energetic ground actions will be conducted when it is impossible to put an airborne platform on station. This is particularly so in the case of conventionally powered (reciprocating engine, propellor driven) aircraft. Since altering the number of similar platforms will not alter the situation, it is suggested that the appropriate point of application of this factor is in determination of the operational acceptability of the platform or of a platform mix.

D. Methodology

Step I. Calculate platform endurance and its components. This will generally be an iterative process with the objective of maximizing on-station time for a given tactical situation. Inputs for the process are the platform performance characteristics commonly expressed by means of graphs for a specified platform model, configuration and loading.

E: Platform endurance.

RT: Reserve flight time required over base on return.

FT: Usable platform time.

$$FT = E - RT$$

TT: Transit time from operating base to operating area.

CT: Climbing time, time required to reach operating altitude.

ERT: Enroute time, time required to reach operating position. Reaching operating position will generally involve a horizontal displacement and/or vertical displacement of the platform. The platform is not on station until both are completed.

$$ERT = \text{Maximum} \begin{cases} TT \\ CT \end{cases}$$

RBT: Time required to return to operating base from operating area. This is not a factor when expendable platforms are being considered.

OST: On-station time, that period of time during which platform position satisfies both altitude and geographic requirements.

The relationships of the components of FT are expressed by the following equation:

$$FT = EPT + OST + RBT$$

TAT: Turn around time, that period of time required to ready an item for use.

OP: Operating period, the period of time required for a platform to complete one operating cycle of flight and turn around time.

$$OP = FT + TAT$$

Step II. Calculate a value for the number of aircraft required to support a specific tactical situation in accordance with the steps listed below:

1. Compute the number of individual sorties per month required:

$$SPM\ (req.) = \frac{(30)(TOS)}{(OST)}$$

2. Compute the number of sorties which one aircraft can fly in one month:

$$SAM = \frac{(EFF)}{(FT)}$$

3. Compute the estimated number of aircraft required on the flight line:

$$FLA\ (est.) = \frac{(SPM\ [req.])}{(SAM)}$$

The accuracy of this estimate may be judged qualitatively and roughly for a given situation and platform FLA (est.) is fairly stable unless OST can vary over a wide range. This will be done in slightly more detail in succeeding steps.

FLA (est.) can be factored as the product of two quotients:

$$\frac{(FT)}{(OST)} \text{ and } \frac{(TOS)(30)}{(EFF)}$$

The first factor will be used later as "the number of aircraft required to be airborne simultaneously." The second is the number of aircraft per month required to provide the coverage required if each aircraft realizes maximum utilization. FLA (est.) results in a value, therefore, which is somewhere between the number of aircraft required on the flight line and the number of aircraft required in the system and may therefore be useful as an estimate of neither. It appears that refinement of the estimate is appropriate.

Step III. Depending on the value of TOS, branch at this point in the computation.

1. TOS = 24, go to step IV
2. TOS < 24, go to step V

NOTE

In the common situation where n stations are supported from the same flight line or launch point, the value OST should be replaced by OST/n wherever it appears. For purposes of scheduling, OST/n is the effective OST. It appears that significant savings may be realized in some cases by supporting as many stations as possible from one launch point due essentially to the shorter effective OST which is the launch interval in a regular launch schedule.

Step IV (TOS = 24). Calculate the number of aircraft required on the flight line.

1. Compute the number of aircraft required to be airborne simultaneously.

$$D = \text{next integer larger than } \frac{(FT)}{(OST)}$$

2. Compute the service time available between landing and the next launch.

$$ST = (D)(OST) - (FT)$$

3. Compute the ratio.

$$R = \frac{TAT}{ST}$$

4. Compute the number of flight line aircraft required to next larger integer.

$$\text{FLA (req.)} = \begin{cases} D + \dfrac{TAT - ST}{OST} & : R > 1 \\ \text{or} & \\ D & : R \leq 1 \end{cases}$$

Step V (TOS < 24). Calculate the number of aircraft required on the flight line.

1. Compute the sorties per day required.

$$\text{SPD (req.)} = \frac{(TOS)}{(OST)}$$

Rounded to the next larger integer

$$\text{SPM (req.)} = (30)\ (SPD)$$

2. Adjust the sortie (OST).

$$\text{OST (adj.)} = \frac{TOS}{\text{SPD (req.)}}$$

3. Adjust the flight time per sortie.

$$\text{FT (adj.)} = FT - OST + \text{OST (adj.)}$$

NOTE

From this point all computed values will be assumed based on adjusted values to obviate the need to write (adj.).

4. Begin a recursive computation to determine the minimum number of flight line aircraft as follows:

$$ST = (K)\ (x) - FT + (OST)\ (y)$$

where

x = 1, 2, ----, N, ----
y = 0, 1, ----, SPD-1
K = the interval between starting each cycle. In the case of one on-station period per day, K equals 24 hours.

Start with $x = 1$, $Y = 0$,
Compute the ratio RF

$$RF = \frac{TAT}{ST}$$

If $RF \leq 1$, go to step VI to determine if FLA can be less than SPD.

NOTE

> A departure from generality is made at this point in that several on-station periods may be scheduled in one day. In that case (K) (x) would be replaced by a sum. However, it is expected that a sufficiently close estimate will be obtained if regular intervals are assumed.

If $RF > 1$, compute the ratio N

$$N = \frac{FT + TAT}{24}$$

Round N to the next integer less than the ratio.

Set $X = N$ and solve for the value of y which makes $R \leq 1$

If $y \leq (SPD - 1)$, then

$$FLA = (N)(SPD) + (y - 1)$$

If $y > (SPD - 1)$, then

$$FLA = (N)(SPD)$$

Step VI. To determine relief cycle/short TAT relationships proceed in accordance with the following steps.

1. Compute the number of aircraft required to be airborne simultaneously.

$$ASA = \text{next integer larger than } \frac{FT}{OST,} \quad D \leq SPD$$

NOTE

ASA will only be greater than SPD when FT is greater than TOS. It would be a ridiculously extreme situation, however, in which more than SPD platforms would be airborne simultaneously. It would require an unrealistic combination of

TOS, very large, approaching 24
FT, very large
OST, very small

so that flights for the next period are launched while current flights are still airborne.

2. Compute the short service time available.

$$SST = (ASA)(OST) - FT$$

3. Compute the ratio RH.

$$RH = \frac{TAT}{SST}$$

If RH > 1, round to the next larger integer and go to Step VI-4 below.

4. Compute the sum S.

$$S = D + RH$$

If $S \leq SPD$, $FLA = (D + RH)$
If $S > SPD$, $FLA = SPD$

<u>Step VII.</u> Calculate the expected flight hours per aircraft per month and adjust FLA if appropriate.

1. Compute the ratio RE.

$$RE = \frac{(30)(TOS)}{FLA + C}$$

where C = 0, 1, 2, ----, M, ----
with C = O
If $RE \leq EFF$, use RE as EFF and do not adjust FLA.

NOTE

This is to the platform's advantage. FLA assumes a maximum schedule. If the schedule can be met with less effort than EFF, any attempt to raise RE is inefficient except for increasing TOS which may be pointless.

If RE > EFF increase C by 1 integer at a time and select that value M which makes RE nearest EFF.

Use FLA (adj.) = FLA + M

Step VIII. Calculate the costs of operating and supporting the platform.

1. Compute the operating costs per month per station maintained.

CPM = (SPM) (FT) (OCH)

where

SPM and FT are computed in either Step IV or Step V.
OCH is obtained by table look-up based on EFF (or RE as in Step VI) as the operating costs per flight hour.

2. Compute the cost of operational support at the appropriate level of flight effort (EFF or RE).

OSC = (FLA) (OSC/Aircraft month)

where

FLA results from the computations of Step VII.
OSC/Aircraft Month is tabulated with respect to EFF.

NOTE

Some tabulations may combine items CPM and OSC, generally in the form used above for CPM.

3. Compute the cost with respect to ground support personnel.

$$GSP = (FLA)(Pers./Aircraft)(Cost/Pers)$$

where

FLA results from the computations of Step VII.
Pers. /Aircraft is commonly tabulated with respect to EFF.
Cost/Pers. may not be available. It may be estimated or "number of persons" may be used as a separate cost measure.

Step IX. Calculation of the number of flight crews required on the flight line can be made to directly parallel the calculation of the number of flight line aircraft required in most cases. The scheme is to treat a flight crew as if it were an aircraft with different performance characteristics. The following substitutions are appropriate:

Instead of	Use this	
OST	FT:	This is the time during which the crew is performing usefully.
FT	ET:	The total time devoted by the flight crew to a sortie. Includes brief, debrief, etc.
TAT	CRT:	A relaxation period between flights. In extremes this can be deleted since nothing in computations precludes TAT = O.

Computations to account for diurnal and periodic extended rest and recreation periods more closely parallel those of overhaul periods in the case of aircraft. With respect to diurnal periodicity a reasonable approximation may be obtained if TOS is taken as 8 hours and the result multiplied by 3.

The number resulting from the computations will represent flight crews required on the flight line (FCR) instead of aircraft required on the flight line (FLA).

Step X. Calculate the number of aircraft (or flight crews) required in the overhaul/operating base cycle.

1. Compute the expected time between overhauls (TBO) for each aircraft.

$$TBO = \frac{HBO}{EFF} \text{ in months}$$

where

HBO is the time in hours between overhauls.
EFF is taken as EFF or RE from

2. Compute the ratio RO.

$$RO = \frac{OHT}{TBO}$$

where

OHT is the time in months required per overhaul.
RO is the ratio of the number of aircraft in overhaul to that number on the flight line.

3. Compute the total number of aircraft required (TAR) per tactical situation and expected overhaul costs.

$$TAR = (FLA)(1 + RO)$$

NOTE

Step X starting with 1 above may be used to estimate the number of flight crews required when periods of R and R are scheduled at regular intervals. Such intervals are probably scheduled by calendar time but it is possible that other criteria, such as number of missions flown, will also apply. In the latter case, the rotation schedule computations more closely parallel those for aircraft where the comparable criterion is flight hours.

4. Compute the expected costs of overhauls per month for FLA.

$$COH = \frac{(FLA)(CPO)}{TBO + OHT}$$

where

CPO is the cost per overhaul.

Step XI. Determine the cost of personnel training. This cost will be some function, as yet undetermined, of the number of personnel, both flight and ground, and of the type platform.

CPT = C (flight crews, ground support pers., platform type)

Step XII. Calculate expected procurement costs.

1. Compute expected losses per month.

LPM = (FT/mo.) (LPH)

where

FT/mo. is the total flight time per month.
LPH is the estimated losses per flight hour.

2. Compute expected procurement costs per month.

$$COP = \frac{TAR}{L} + LPM\ CPU$$

where

L is the expected life of the platform in months.
CPU is the cost per unit platform.

Step XIII. Calculate the cost of non-expendable ground support items per month.

$$CGA = \frac{\text{Cost of items}}{L}$$

where L is the expected life of each item in months.

Step XIV. Calculate the cost of supporting a remote launch point (CRS) when required. Determination of this cost item requires information not yet available. Consideration of the overall cost should include it, however. There will be a cost trade-off between the savings realized by shortening the distance from launch point to operating area, and the cost of supporting the remote station. The cost will be some function of the flight effort supported from that station and its remoteness from a resupply point.

CRS = C (FLA, FT, distance to resupply point)

Step XV. Calculate the total ccsts per month.

Item	Step	Factors	Cost: \$/mo.
CPM	VII-1	N (SPM)(FT)(OCH)	
OSC	VIII-2	N (FLA)(OSC/ACMo.)	
GSP	VIII-3	N (FLA)(Pers.)(Cost)	
FCP	IX	N (FCR)(Pers.)(Cost)	
COH	X-4	N (COH)	
CPT	XI		
COP	XII-2		
CGS	XIII		
		Total	

4.5.4.3.2 Cost Tabulation Example Used in Cost-Effectiveness Model. Costs of supporting the II Corps Area on a 24-hour-a-day basis with complete coverage of the area are presented as an example of cost-effectiveness model cost tabulations.

Table 4-8 lists costs for four manned aircraft in three cost categories. The aircraft are UH-1, O-1E, YAT-37D, and C-130. Cost categories are direct operating costs in dollars, number of flight crews required, and number of aircraft on the flight line. Direct dollar operating costs include flight expendables.

In making the computations for spares consumed and maintenance manpower, two basic operational situations are applied. For the UH-1 and O-1E, 24 stations are continuously manned from 9 airfields, each of which is within 25 miles of the operating area. For the YAT-37D and C-130, 3 stations are continuously supported from 2 airfields within 100 miles of the operating area. It was necessary to short circuit the cost effectiveness due to insufficient time and lack of firm data. For example, Turn Around Time (TAT) had to be estimated. Consequently, a number of items could not be realistically estimated, the more significant of which are listed below.

A. Flight Crews. The number of personnel per flight crew may vary substantially. The training requirement is not known but from an operating standpoint it would seem that very little additional training would be required since the flight operations are basic. With respect to the relay however, in the case of large aircraft with long endurance, in-flight maintenance may be feasible indicating possible technical training. Such training might be most economically performed at a service school.

B. Aircraft Procured. Computations did not include a number for aircraft in overhaul. Nor does it allow for mission aborts due either to aircraft or relay malfunctions. Aircraft price is not presently available for all platforms.

C. Remote Support Operations. Additional costs of supporting operations at the outlying (or remote) stations is not considered. This may well be a significant item.

D. Housekeeping Costs. Housekeeping costs generally are not included and input data is not currently available.

Table 4-8. Typical Cost Figure for Supporting the 2nd Corps Area Continuously with Types of Manned Aircraft Platforms.

Cost Item	PLATFORM			
	UH1	O1F	YAT-37D	C-130
Consumables	156, 000	43, 600	40, 500	190, 640
Spares Consumed	333, 000	1 30, 800	34 700	200, 000
Manpower (Maint.)	605, 000	3 93, 000	72, 200	377, 000
Total (Dollar)	1,094, 800	567, 400	147, 400	767, 640
Flight Crews Required	108	108	15	18
Flight Line Aircraft Required	144	108	18	12

4.5.4.3.3 Typical Cost Tabulations

A. UH-1 Utility Helicopter. Three operations supported from each of 9 remote stations gives:

E = 3 hours (180 minutes)

$$\text{ERT} = \left(\frac{25}{130}\right) 60 = 12 \text{ minutes}$$

ERT + RBT = 24 minutes

OST 156 minutes

OST (eff.) = 52 minutes

*FLA = 4

$$\text{SPM} = \frac{(30)(24)(60)}{(52)} = 830/\text{station}$$

*FTM = (830)(3) = 2490 flight hours/mo. per aircraft = 620.

Therefore, FLA will be multiplied by 3 or 4 to make time per aircraft month reasonable, on the order of 150-200 FLA ≈ 16

FLA ≈ 16

FLP = 12 crews for 8-on/16-off cycle.

GSP

2nd Corps FTM = (9) (2490) = 22,400

FCP = 108 crews

FLA = 144 aircraft

CPM	=	(22,400) (7)	=	$ 156,800
Spares Cons.	=	(22,400) (14)	=	333,000
Manpower (Maint.)	=	(22,400) (27)	=	605,000
				$1,094,800

Flight Crews required	108
Procured A/C	144

B. <u>O-1E Observation Aircraft.</u> Three operations supported from each of 9 remote stations gives:

E	=	5 hours (300 minutes)
ERT	=	$\frac{25}{104}$ (60) = 16 minutes
ERT + RBT	=	32 minutes
OST	=	268 minutes
OST (eff.)	=	89 minutes
*FLA	=	3
SPM	=	$\frac{(30)(24)(60)}{(89)}$ = 486/station
FTM	=	(486) (5) = 2430 per A/C = 810
*FLA	=	12
FCP	=	12 crews
2nd Corps FTM	=	(9) (2430) = 21,800

CPM	=	(21,800) (2)	=	$ 43,600
Spares Cons.	=	(21,800) (6)	=	130,800
Manpower (Maint.)	=	(21,800) (14)	=	393,000
				$567,400

Flight crews required (9) (12)	108
Procured A/C	108

C. <u>YAT-37D Fixed-Wing Aircraft.</u> Two operations are supported from one major airfield.

E	=	2.5 hours (150 minutes)
ERT	=	$\frac{100}{320}$ (60) = 19 minutes
ERT+RBT	=	38 minutes
OST	=	112 minutes

OST (eff.) = 56 minutes

D = 2.7 (3)

FLA = 4

SPM $= \dfrac{(30)(24)(60)}{(56)} = 772$

FTM = (772) (2.5) = 1930 per aircraft = 482

FLA ≈ 12

FCP ≈ 9

One operation supported from one major airfield.

E = 2.5 hours (150 minutes)

ERT + RBT = 38 minutes

OST = OST (eff.) = 112 minutes

D = 2

FLA = 4

SPM $= \dfrac{(30)(24)(60)}{(112)} = 385$

FTM = (385) (2.5) = 960 per A/C = 480

FLA = 6

FCP = 6

2nd Corps FTM = (960) + (1930) = 2890

FCP ≈ 15

FLA ≈ 18

CPM	=	(2890) (14)	=	\$ 40,500
Spares Cons.	=	(2890) (12)	=	34,700
Manpower (Maint.)	=	(2890) (25)	=	72,200
				\$147,400

Flight crews required	15
Procured A/C	18

D. <u>C-130 Transport Aircraft.</u> Two operations supported from one major airfield.

$$E = 9 \text{ hours } (540 \text{ minutes})$$

$$ERT = \frac{100}{280}(60) = 22 \text{ minutes}$$

$$ERT + RBT = 44 \text{ minutes}$$

$$OST = 496 \text{ minutes}$$

$$OST\ (\text{eff.}) = 248 \text{ minutes} \quad (\text{Assume TAT 2 hours})$$

$$D = 3$$

$$FLA = 4$$

$$SPM = \frac{(30)(24)(60)}{(248)} = 175$$

$$FTM = (175)(9) = 1575 \text{ per aircraft} = 394$$

$$FLA \approx 8$$

$$FCP \approx 12$$

One operation supported from one major airfield

$$E = 9 \text{ hours } (540 \text{ minutes})$$

$$ERT + RBT = 44 \text{ minutes}$$

$$OST = OST\ (\text{eff.}) = 496 \text{ minutes}$$

$$D = 2$$

$$FLA = 2$$

$$SPM = \frac{(30)(24)(60)}{(496)} = 87$$

$$FTM = (87)(9) = 783 \text{ per aircraft} = 392$$

$$FLA = 4$$

$$FCP = 6$$

2nd Corps FTM	=	(783) + (1575)	=	2358
FCP	=	18		
FLA	=	12		

CPM	=	(2358) (80)	=	$190.640
Spares Cons.	=	(2358) (85)	=	200,000
Manpower (Maint.)	=	(2358) (160)	=	377,000
				$767,640

Flight crews required	18
Procured A/C	12

4.5.4.3.4 Quantity of HARR Platforms Required. The quantity of HARR platforms required depends on several factors. These factors are related to both the mission requirements and the platform capability. Mission requirements are not well established, and will vary from month to month as the operational situations change. Furthermore, platform capabilities vary for the different candidates, and the HARR system may very likely make use of a platform "mix" (a combination of different candidates). Thus, a specific quantity of platforms needed for HARR cannot be determined at this time.

The following paragraphs describe the factors that determine the number of platforms needed. The discussion pertains specifically to manned military aircraft candidates, but is intended to be general enough to apply to other possible platforms. By referring to the discussion, platform quantity requirements can be determined, once mission requirements and platform capabilities have been specified.

The factors considered are:

A. The number and location (altitude and over ground position) of the platform stations.

B. The length of time (period of duration for each assignment and total hours each month) stations are required.

C. The scheduling capability of each candidate (how often it can be assigned to a station and what portion of the scheduled flight is effective time on station).

D. The reliability of each candidate (i.e., the degree of probability that the platform will be able to continue satisfactory operation).

It should be noted that neither the navigational nor the inclement weather limitations are considered. It is assumed that each platform capable of operating can navigate to the station location; and if the weather prevents operation of a particular candidate, increasing the numbers of that candidate serves no purpose.

Concerning the number and location of the platform stations, the requirements for relay repeaters generated by a particular military operation can be met by any one of several possible configurations of station positions and altitudes. Station configurations are most likely to have a significant influence on the quantity of platforms required when the number of stations simultaneously provided is a maximum. An upper limit on the stations needed can be determined by considering the more extensive military operations and the particular station configuration, of all the probable configurations, which requires the most stations. This type of station configuration analysis should consider the possibility of using different platforms at different altitudes, and, thus, should determine an upper limit on the stations required in the different altitude ranges. For instance, an analysis may show that six stations between 5,000 feet and 10,000 feet, and two stations between 20,000 feet and 25,000 feet would meet the requirements of a particular operation. It may also show that four stations between 20,000 feet and 25,000 feet is a second probable way of meeting the requirements. Then, the upper limit on stations needed simultaneously between 5,000 feet and 10,000 feet is six, and the upper limit on stations needed simultaneously between 20,000 feet and 25,000 feet is four. Suppose the UH-1D's have been chosen as platforms to operate between 5,000 feet and 10,000 feet, and the U-8F's have been chosen as platforms to operate between 20,000 feet and 25,000 feet. Then, platform requirements based on the number and location of platform stations would be six UH-1D's and four U-8F's. This provides one platform for each station for the situation of maximum simultaneous station requirements.

As to the length of time stations are required, each aircraft is limited to the time it can stay on station by its endurance. When mission requirements call for continuous use of a station for a longer period than can be provided by a single flight, flights have to be scheduled to provide continuing coverage. In addition to influencing scheduling, endurance determines the percentage of the aircraft flight time that is effective time on station. Effective time on station equals the total flight time minus the transit time to and from the station. For a given transit time, the percentage of effective time on station increases as the endurance increases. In addition to its endurance limit, each aircraft has a maximum monthly flying hour utilization. The combination of monthly flying hours and effectime time on station gives a maximum number of hours on station each aircraft can provide. As the station altitude increases, the time to station increases and the time on station decreases; thus, the hours on station per month decreases. Enough platforms must be provided to provide the required hours on station.

A caution given by Army Aircraft Project Office members at AVCOM was that for a mission as monotonous and long as would be characteristic of HARR, the human endurance often would become a more limiting factor than the on-station endurance time of the aircraft. Figure 4-16 is a chart which gives an example of the special consideration that was given to a pilot's ability to spend long hours confined within the narrow limits of an O-1E cockpit. Flight hours, i.e., on-station hours plus station taking and base return hours, are divided to obtain the abscissa values. Because the human endurance is appreciably less than O-1E aircraft endurance at each indicated HARR station altitude, the human endurance curve falls consistently farther to the right. The other important critical values used to make up the curves are also presented on the chart.

As to the scheduling capability of each candidate, when a single flight does not have the endurance to provide a station as long as it is required, a second platform must relieve the first. Continuous coverage is provided by scheduling. The number of platforms needed depends on the scheduling technique and the capability of each platform to cycle through time on station, return to base, preparation for flight, and flight to the station. The scheduling technique which requires the minimum aircraft is shown in Table 4-9. It consists of staggering the arrival and departure of aircraft at the base, so that each aircraft is reassigned to a station as soon as possible after its turnaround preparation is complete. This type of staggered scheduling would not be needed if the total on station hours per month, divided by the maximum simultaneous stations was considerably more than the aircraft monthly hours on station. The following equation can be used to determine the number of aircraft required for scheduling needs.

$$N_p = NS\left[\frac{T_1 + T_2 + T_3}{T_1}\right]$$

where: N_p is the number of platform needed

NS is the maximum of simultaneous stations

T_1 is the time on station

T_2 is the time in transit to and from the station

T_3 is the time on the ground for aircraft turnaround

Scheduling tends to become a critical factor as the ratio of $T_1 + T_2 + T_3$ to T_1 becomes large, and the ratio of total on-station hours to maximum simultaneous stations approaches the monthly hours on station per aircraft.

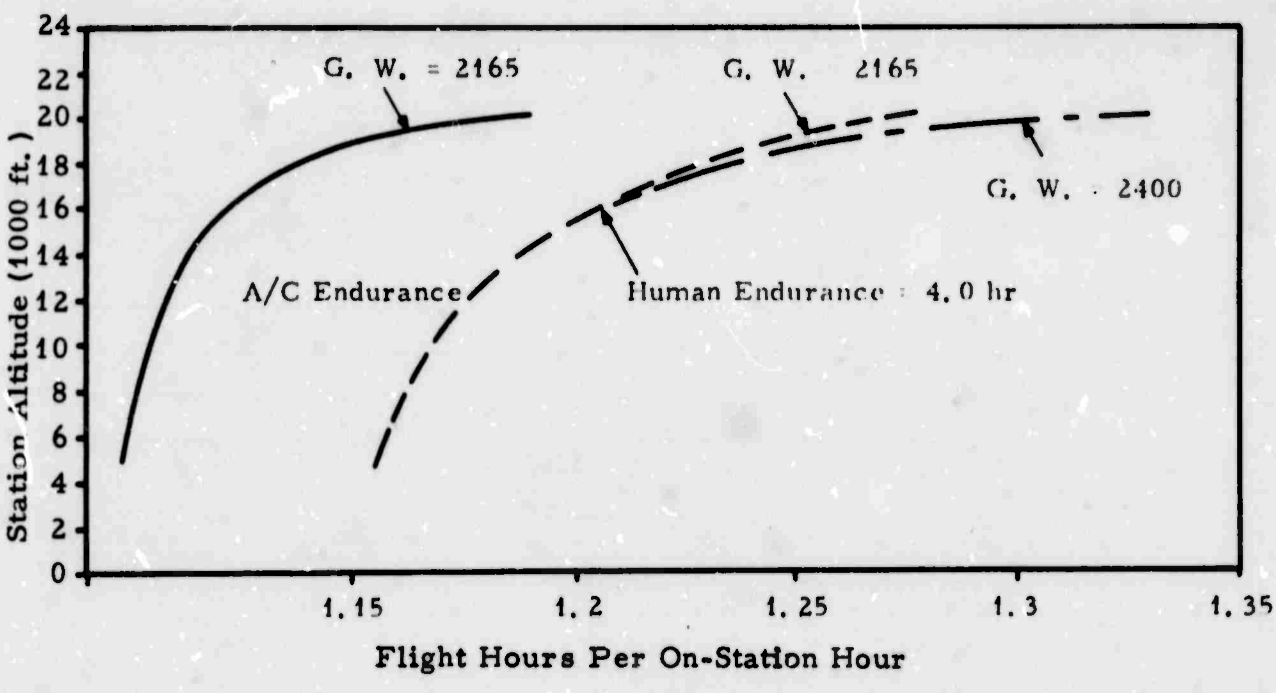
Fuel to Return:

Assume - TAS = 120 mph

Fuel Flow = 5.5 gph

Fuel - $\frac{30}{120}$ 5.5 = 1.4 gal.

Time - $\frac{30}{120}$ = 0.25 hr = 15 min.



Operating Costs:

Assume -

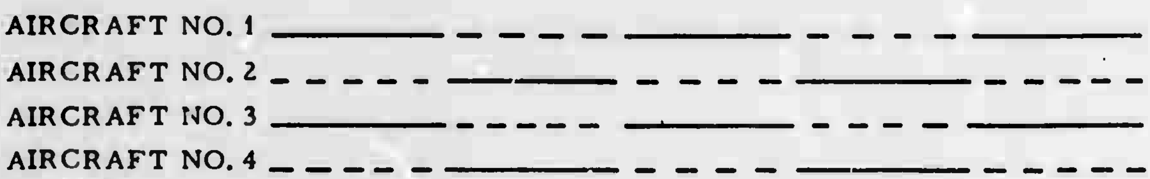
1. Direct Operating Cost = $24 / Hour
2. 720 On-Station Hours / Month
3. No. Vehicles Required / Situation and Area as per R. West Report
4. Flight Endurance / Human Limited to 4.0 Hours
5. 30 Mile Cruise Distance to Station

Figure 4-16. O-1E Endurance Curves

Table 4-9. Staggered Platform Scheduling

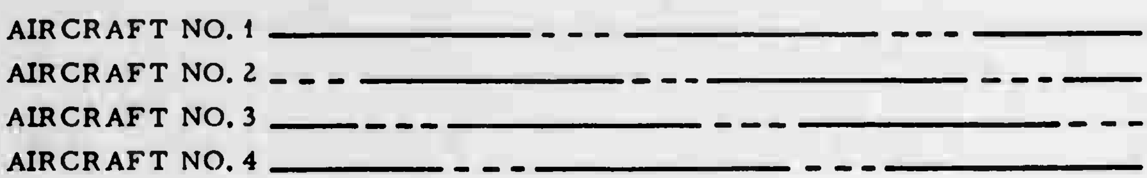
STAGGERED PLATFORM SCHEDULING

CASE 1 $\dfrac{T_1 + T_2 + T_3}{T_1} = 2$



TWO STATIONS COVERED SIMULTANEOUSLY BY FOUR AIRCRAFT

CASE 2 $\dfrac{T_1 + T_2 + T_3}{T_1} = \dfrac{4}{3}$



THREE STATIONS COVERED SIMULTANEOUSLY BY FOUR AIRCRAFT

T_1 IS TIME ON STATION

T_2 IS TIME IN TRANSIT TO AND FROM THE STATION

T_3 IS TIME ON THE GROUND FOR AIRCRAFT TURN AROUND

LEGEND

——— TIME SPENT ON STATION (T_1)

- - - - - - TIME SPENT OFF STATION $(T_2 \pm T_3)$

Concerning the reliability of each candidate, it is known that, since some aircraft will be lost through attrition and others will fail to operate when needed, backup aircraft are needed. The number required for backup is determined by considering the number of aircraft committed to the HARR mission and the reliability of each aircraft. If ten aircraft are committed (either in flight or in the flight line for turnaround) and the reliability of each aircraft is 90%, then normally one aircraft will be inoperable. However, the possibility is not too remote that two aircraft will be inoperable. But if one hundred are committed, there will nearly always be ten inoperable, and almost never will there be twenty inoperable at the same time. A mathematical expression for backup requirements can be provided; but for the actual operation, it probably does not have much meaning. Enough aircraft will be needed to cover the peak activity periods. If some of the aircraft are inoperable, the lower priority stations will not be provided. If activity decreases and aircraft become available, the lower priority stations will be provided. Where platform reliability is 80% or greater, backup requirements are probably overshadowed by the range between what a commander would like to provide and what he must provide to conduct an operation. Where platform reliability is below 80%, backup platforms may be required before an operation would be started.

The number of platforms needed will be determined either by the requirement to provide the specified total hours on station, or to provide the specified maximum number of stations. The number needed to provide the hours on station is determined from the total hours required, the hours provided per aircraft, and the requirement for backup aircraft. The number needed to provide the stations is a function of the number of stations, scheduling, and backup requirements. Equations for the number of stations needed are as follows:

To provide needed hours on station:

$$N_1 = \frac{H_T}{H_p} \times \frac{1}{R} \quad \text{rounded to next higher whole number}$$

where: H_T is the total hours on station in a month

H_p is the hours on station per month per platform

R is the reliability of the platform

To provide needed stations:

$$N_2 = NS \left[\frac{T_1 + T_2 + T_3}{T_1}\right] \times \frac{1}{R} \quad \text{rounded to next higher whole number}$$

where: R is the reliability of the platform.

The larger of N_1 or N_2 will determine the number of platforms needed. The conditions that tend to make N_1 larger than N_2 are: When there are about the same number of stations required throughout a month and these stations are required more hours than a single platform can provide; or when turnaround time and transit time are small compared to endurance. The conditions that tend to make N_2 larger than N_1 are: When there are large numbers of stations needed for periods longer than can be provided by a single flight, but for less hours per month than a single platform can provide; or when turnaround time and transit time are large compared to endurance, this would require several aircraft per station. Table 4-10 lists the number of aircraft needed for from 1 to 14 stations, and thirteen different ratios of $T_1 + T_2 + T_3$ to T_1 (ranging from 4 to 8/7). When the number is not a whole number, the next higher whole number is the quantity of aircraft needed to schedule continuous station coverage.

Table 4-10. Aircraft Requirements

$\frac{T_1+(T_2+T_3)}{T_1}$	NS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(1+3)/1 = 4	4	8	12	16	20	24	28	32	36	40	44	48	52	56
(1+2)/1 = 3	3	6	9	12	15	18	21	24	27	30	33	36	39	42
(1+1.6)/1 = 2.6	2.6	5.2	7.8	10.4	13	15.6	18.2	20.8	23.4	26	28.6	31.2	33.8	36.4
(1+1.4)/1 = 2.4	2.4	4.8	7.2	9.6	12	14.4	16.8	19.2	21.6	24	26.4	28.8	31.2	33.6
(1+1.2)/1 = 2.2	2.2	4.4	6.6	8.8	11	13.2	15.4	17.6	19.8	22	24.2	26.4	28.6	30.8
(1+1)/1 = 2	2	4	6	8	10	12	14	16	18	20	22	24	26	28
(1.5+1)/1.5 = 1+2/3	1+2/3	3+1/3	5	6+2/3	8+1/3	10	11+2/3	13+1/3	15	16+2/3	18+1/3	20	21+2/3	23+1/3
(2+1)/2 = 1+1/2	1+1/2	3	4+1/2	6	7+1/2	9	10+1/2	12	13+1/2	15	16+1/2	18	19+1/2	21
(3+1)/3 = 1+1/3	1+1/3	2+2/3	4	5+1/3	6+2/3	8	9+1/3	10+2/3	12	13+1/3	14+2/3	16	17+1/3	18+2/3
(4+1)/4 = 1+1/4	1+1/4	2+1/2	3+3/4	5	6+1/4	7+1/2	8+3/4	10	11+1/4	12+1/2	13+3/4	15	16+1/4	16+1/2
(5+1)/5 = 1+1/5	1+1/5	2+2/5	3+3/5	4+4/5	6	7+1/5	8+2/5	9+3/5	10+4/5	12	13+1/5	14+2/5	15+3/5	16+4/5
(6+1)/6 = 1+1/6	1+1/6	2+1/3	3+1/2	4+2/3	5+5/6	7	8+1/6	9+1/3	10+1/2	11+2/3	12+5/6	14	15+1/6	16+1/3
(7+1)/7 = 1+1/7	1+1/7	2+2/7	3+3/7	4+4/7	5+5/7	6+6/7	8	9+1/7	10+2/7	11+3/7	12+4/7	13+5/7	14+6/7	16

4.5.5 Cost and Effectiveness of HARR. All of the previous subsection plus tables contained in this subsection constitute the basis for this discussion. The object of this discussion is to combine the meaningful elements of Subsection 4.5.4 into a form which will enable a comparison of the HARR initial platform candidates on a cost/effectiveness basis.

4.5.5.1 Cost. Paragraph 4.5.4.2 deals extensively with HARR platform costs. Of the many possible ways of representing those costs, the following is appropriate to the form in which the most recent data is tabulated and is consistent with previous cost presentations.

Cost = Direct Operating Cost (DOC) + Procurement (PROC) + Base Operating Support (BOS)

The dimensions of each component are dollars per unit time when possible. An example of the difficulty of assigning dimensions is that of initial procurement. It would be necessary to ascribe a useful life to each platform procured in order to express its costs in dollars per unit time. Procurement costs due to attrition, however, may be so expressed since expenditures for replacement platforms are assumed to occur at the same rate with respect to time as losses.

4.5.5.1.1 Direct Operating Cost (DOC). The DOC's used in this discussion are listed in Table 4-11 which was obtained from AVCOM. Available data, as presented in paragraph 4.5.4.2, indicate that operating costs are not strictly linear functions of flight hours. For simplicity, however, they will be treated as if they were. Operating costs will be determined from the following expression

$$(OST)\ (FF)\ (Cost/FH)\ (N)$$

where:

OST is the number of on-station hours required per month. Maximum is taken as 720.

FF is the flight factor or ratio of number of hours flight time required in providing one hour on station. Flight factors are taken from previous subsections when available.

$$FF = \frac{FH}{OST}$$

Cost/FH is the dollar value of maintenance and operating costs per flight hour taken from Table 4-11.

N is the number of stations maintained for the case within the platform capability.

Table 4-11. Army Aircraft Maintenance and Operating Cost per Flight Hour

Aircraft Systems	(Maintenance Costs)								Operating Cost		Total Maintenance & Operating Costs	
	Labor Costs			Parts Costs (1)			Depot Parts and Labor	Total Maint	Fuel Oil	Flight crew (3)		Bos. Est
	Orgn Maint	Direct Support	General Support	Orgn Maint	Direct Support	General Support						
0-1	2.84	1.39	1.46	1.10	.30	.55	3.74	11.38	1.93	4.47	17.78	56.50
U-6	3.02	1.99	2.04	1.55	.40	.75	9.81	19.56	4.91	4.47	28.94	65.50
U-8	4.35	2.39	1.46	2.50	1.00	1.00	10.95	23.65	7.50	10.05	41.20	65.50
U-1	3.97	2.59	2.63	1.75	.75	1.15	19.64	32.48	6.74	11.04	50.26	61.00
CV-2B	9.64	4.58	4.09	2.00	4.00	5.00	86.43	115.74	28.83	9.35	153.91	*63.00
OH-13	3.59	1.99	2.34	.70	.80	2.00	13.93	25.35	3.40	4.47	33.22	74.00
OH-23	3.59	2.19	2.34	1.40	1.90	2.00	11.76	25.18	3.62	4.47	33.27	
UH-1	5.48	2.99	3.21	1.93	2.53	1.21	40.38	57.73	8.28	10.71	76.72	60.00
UH-19	6.99	6.57	5.26	2.00	3.00	1.50	39.50	64.82	12.22	4.47	81.51	
CH-21	10.96	7.76	5.84	3.40	4.30	2.90	58.53	93.69	18.14	11.04	122.87	
CH-34	10.77	6.77	6.72	3.30	4.20	2.70	48.08	82.54	20.97	11.04	114.55	
CH-37	17.01	10.75	10.51	4.00	6.00	5.00	132.28	1[illegible]5.55	37.60	12.71	235.86	
CH-47	17.96	11.54	10.80	25.00	15.00	10.00	306.30	396.60	43.41	11.80	451.81	
CH-54	13.23	5.95	5.81	76.00	38.00	13.00	523.00	674.99	70.92	11.80	757.71	
OH-6	2.33	1.71	1.64	2.00	1.00	1.00	(2) 17.20	26.88	2.63	4.47	33.98	

(1) Expendables
(2) Excludes End Item Depot Maintenance
(3) Source AR 35-247- Superceded by AR 37-29

* For CV-2 in reference (b). Note that correlation is not direct between BOS and Maintenance Operation costs.

4.5.5.1.2 Procurement. Procurement is considered as a two-stage process. First is initial procurement which is stated as a lump sum since the useful life of each platform is not known. Initial procurement is determined from the following expression:

$$\frac{(FH)}{(U)(A)}$$

where

FH is the number of flight hours per month to be flown by the platform. FH = (OST)(FF).

U is the utilization of the platform in hours per month.

A is the platform availability taken from Table 4-12. This table was also obtained from AVCOM.

Procurement to replace attrition losses is expressed as a monthly dollar expenditure as follows:

$$(FH)(AH/FH)$$

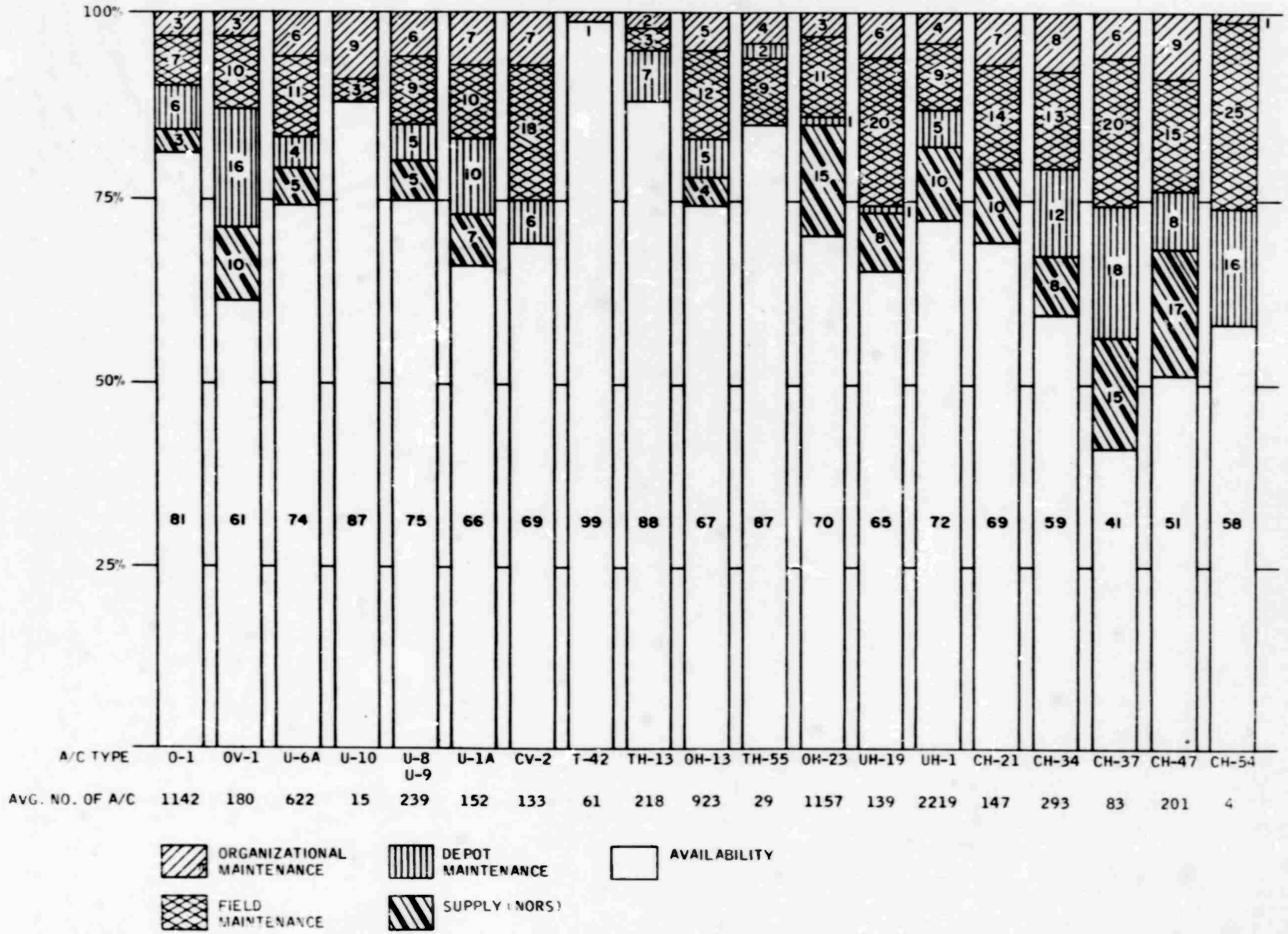
where:

FH is the number of flight hours flown by the platform per month.

AH/FH is the dollar rate of attrition replacement from sub-section 4.5.4.2.

4.5.5.1.3 Base Operating Support. Base Operating Support (BOS) is not included in the calculations made in this subsection. This is regrettable since BOS may be more significant than DOC, particularly in view of the difficulties which may be encountered in establishing and supporting remote bases. Available data do not reflect such factors and are most likely determined as a "fair share" portion of the operation of an established base of operations. The basis for "fair share" allocations is not known but may well be number of personnel supported. BOS figures presented in paragraph 4.5.4.2.1 required estimation in some cases but are based on the best data obtained. It should be noted that the variability in BOS dollars per flight hour listed in paragraph 4.5.4.2.1 is not nearly so great as the variability in maintenance and operating costs per flight hour listed Table 4-11. Thus the contribution to "spread" of BOS is less. Therefore, BOS is ignored in this presentation on the grounds that, when known, its contribution to variability is small compared to that of maintenance and operating costs. It is of interest that correlation of BOS with Maint/Op costs is not

Table 4-12. US Army Aircraft Availability and Downtime



direct. The objection to use of BOS as generally known is that operation of an aircraft such as the O-1E from remote fields may exceed that of the U-8, which, due to its all-weather capability, may best be operated from a major airfield.

4.5.5.2 Effectiveness. Definition of a suitable measure of effectiveness for HARR has been troublesome due to the "apples vs oranges" nature of the choice to be made. For example, the O-1E aircraft is very inexpensive to operate. Even though equipped with DF (Direction Finding) radio equipment, it is a single pilot craft and precision navigation is out of the question. HARR station keeping must, therefore, be by visual reference to the ground. If 24-hour operations are anticipated, the O-1E simply cannot meet the requirement for night operations by itself. Furthermore, some manned aircraft (e.g., the O-1E) are more sensitive to inclement weather than others (e.g., the U-8). An instrument qualified aircraft can climb to and maintain HARR station with only nominal reference to the ground during takeoff and landing. For purposes of this discussion it is assumed that aircraft such as the O-1E require a ceiling of no less than 5,000 feet. (The 5,000 feet is the minimum altitude to avoid groundfire, and the aircraft must be able to maintain visual reference to the ground.) Weather factors are taken as the most severe of those presented in Table 4-13.

Effectiveness is expressed by:

$$(FH)(W)(R)$$

where:

FH is the number of flight hours per month which the aircraft is capable of providing. The maximum for an aircraft which is restricted to daylight operations is assumed to be 360.

W is the weather factor (Table 4-13) or the percentage of the total time capability during which weather does not preclude flight operations. It is assumed that this factor is independent of the time of day, that is, daylight vs darkness.

R is the relay reliability factor which is not considered here.

4.5.5.3 Cost vs Effectiveness. In this discussion, cost plotted versus effectiveness is a straight line due to the assumed nature of the cost function. The cost/effectiveness ratio is the slope of that line which is simply cost per flight hour. This measure is appropriate only for the number of flight hours per month which the platform can provide. For a requirement in excess of that number the measure is not defined for that platform.

Table 4-13. Weather Distribution of Southeast Asia

Country and Region	Percentage Frequency of Specified Ceiling (Annual)				Percentage Frequency of Specified Visibility Ranges (Annual)				Percent of time Ceiling ≥ 1000ft. Visibility ≥ 2 1/2 mi. (Ann.)	Mean No. of Days with Thunderstorms
	<650'	<1000'	<2000'	<5000'	<1/2mi	<1 mi.	<2mi.	<5mi.		
South Vietnam Mekong Lowlands (Saigon)	2	4	9	16	1	3	6	15	92	48
East Coast (Nha Trang)	<0.5	1	6	18	<0.5	<0.5	1	5	99	9
East Coast (Tourne)	3	7	12	24	2	4	8	18	89	18
Cambodia West Lowlands (Phom Penh)	1	2	8	22	<0.5	1	2	4	83	51
Siem Reap	1	2	8	36	<0.5	0.5	1	2	97	22
Loas Luang Prabung	Data	Not	Avai	lable	<0.5	2	5	20	Data Not Available	27
Seno	2	5	11	20	1	2	5	27	93	Data Not Available
Vientiane	2	4	7	12	6	9	14	31	85	80

4.5.5.4 Calculations. The results of calculations made must be considered with respect to the assumptions made and the input data. These results must not be considered as final. Further investigation is required in order to arrive at a realistic cost factor. Some examples of missing data have been cited and there are others, the end result of which may completely obscure the factor of maintenance operating costs.

4.5.5.5 Factors. The more significant factors affecting maintenance and operating costs and costs related to purchase of manned aircraft platforms are listed in Table 4-14. These are generally extracted from previous cost tables. One exception is the flight factor for the O-1E aircraft which is very sensitive to payload. It was found to be less expensive to use the 300-lb relay in Case 4 (subsection 4.5.4.1.2) even at the higher flight factor of 1.4 than to use the 100-lb relay at flight factor 1.2 due to the higher number of stations required with a smaller number of channels per platform.

Case 4 is considered appropriate for Army aircraft. The altitudes are within the capabilities of the aircraft and the aircraft cannot operate effectively at the altitudes required for Cases 5 and 6 in mountainous terrain.

Table 4-15 lists the results of calculations to determine maintenance and operating costs for maintaining a single station and 4 stations (as in Case 4) with the aircraft listed in Table 4-15. (Under the assumptions made, one is simply 4 times the other.)

Table 4-16 lists the results of calculations to determine the number of platforms to be procured initially, the cost of initial procurement, and the cost of replacements due to expected losses. Calculations were based on a 4-station battalion situation and were carried out only for those aircraft for which a procurement price was reasonably known. The latter could be included in operating costs but was not due to the low confidence of attrition data. The results are sensitive to the assumed values of utilization (75 hours per month) and number of stations (4). Doubling the utilization, which is not unreasonable for some fixed wing aircraft, and halving the number of stations will reduce to a quarter the number of required platforms as listed in Table 4-6.

4.5.5.6 Cost-Effectiveness Curves. Figures 4-17 and 4-18 show the results listed in Table 4-15. Monthly maintenance and operating costs are plotted against hours coverage provided per month. When the latter is used as a measure of effectiveness, the cost/effectiveness ratio is simply the slope of the line. As mentioned earlier, however, the measure is not defined where the platform capabilities are exceeded. For example, the O-1E is the platform with the lowest cost/effectiveness ratio but it cannot satisfy the requirement if night coverage is required. The next best cost/effectiveness ratio appears to be for the U-6 which can operate at night, from grass fields, etc.

Table 4-14. Manned Aircraft Computation Factors

Type of Aircraft	Diurnal Capability %	Weather Capability %	Flight Factor FH/OST	Utilization Rate Hours/Mo.	Attrition Rate A/C/FH	Availability %	Maintenance & Operation Cost $/FH
O-1 *	50	82	1.4	75	15×10^{-5}	81	17.78
U-6 *	100	99	(1.1)	75	13×10^{-5}	74	28.94
U-8 *	100	99	1.1	75	13×10^{-5}	75	41.20
U-1 *	100	99	(1.1)	75	13×10^{-5}	66	50.26
CV-1 *†	100	99	(1.1)	(75)	13×10^{-5}	61	153.91
OH-13 *	50	82	(1.3)	50	44×10^{-5}	67	33.22
OH-23	(50)	82	(1.3)	(50)	31×10^{-5}	70	33.27
UH-1 *	100	82	1.3	50	(30×10^{-5})	72	76.72
UH-19	(100)	82	(1.3)	(50)	(30×10^{-5})	65	81.51
CH-21 ‡	(100)	82	(1.3)	(50)	(30×10^{-5})	69	122.87
CH-34	(100)	82	(1.3)	(50)	(30×10^{-5})	59	114.55
CH-37	(100)	82	(1.3)	(50)	(30×10^{-5})	41	235.86
CH-47	(100)	82	(1.3)	(50)	(30×10^{-5})	51	451.81
CH-54	(100)	82	(1.3)	(50)	(30×10^{-5})	58	757.71
OH-6	(100)	82	(1.3)	50	(30×10^{-5})	(55)	33.98

*"Prime" candidate.

†Assumed to be comparable to the CV-2.

‡Phased-out aircraft; may be attractive from a procurement point of view.

NOTE: Numbers in parentheses are strictly estimates.

Table 4-15. Platform Maintenance and Operating Costs

Type of Aircraft	Duty Capability %	Duty Hours per Month	Flight Factor	Flight Hours per Month	$/Month per Station	No. of Stations (Case 4)	Cost per Month $ (per Battalion)
O-1 *	41	295	1.4	413	7,340	4	29,300
U-6 *	99	713	1.1	784	22,700	4	90,800
U-8 *	99	713	1.1	784	32,300	4	129,000
U-1 *	99	713	1.1	784	39,400	4	157,500
CV-1 *	99	713	1.1	784	120,500	4	482,000
OH-13 *	41	295	1.3	383	12,700	4	50,900
OH-23	41	295	1.3	383	12,700	4	50,900
UH-1 *	82	590	1.3	766	58,900	4	235,000
UH-19	82	590	1.3	766	62,500	4	250,000
CH-21	82	590	1.3	766	94,100	4	376,000
CH-34	82	590	1.3	766	87,800	4	351,000
CH-37	82	590	1.3	766	180,500	4	722,000
CH-47	82	590	1.3	766	346,000	4	1,382,000
CH-54	82	590	1.3	766	580,000	4	2,320,000
OH-6	82	590	1.3	766	26,000	4	104,000

*"Prime" candidate.

Table 4-16. Procurement Related Costs (Platform Only)

Type of Aircraft	Unit Price ($1,000)	Flight Hrs/Mo.	Utilization Hrs/Mo.	Availability %	Initial Proc. No. A/C per Battalion	Initial Proc. ($1,000)	Attrition Rate A/C per FH	Proc./Mo. A/C	Proc./Mo. $
O-1 *	19	413	75	81	28	532	15×10^{-5}	0.248	4,800
U-6 *	98	784	75	74	57	5,580	13×10^{-5}	0.407	39,900
U-8 *	114	784	75	75	57	6,500	13×10^{-5}	0.407	46,200
U-1 *	122	784	75	66	64	7,810	13×10^{-5}	0.407	49,700
CV-1 *	725	784	75	61	69	50,000	13×10^{-5}	0.407	294,500
OH-13 *	55	383	50	67	46	2,530	44×10^{-5}	0.674	38,720
OH-23		383	50	70	44				
UH-1 *	247	766	50	72	86	21,250	30×10^{-5}	0.919	227,000
UH-19		766	50	65	95				
CH-21		766	50	69	89				
CH-34		766	50	59	104				
CH-37		766	50	41	150				
CH-47		766	50	51	120				
CH-54		766	50	58	106				
OH-6		766	50	55	112				

*"Prime" candidate.

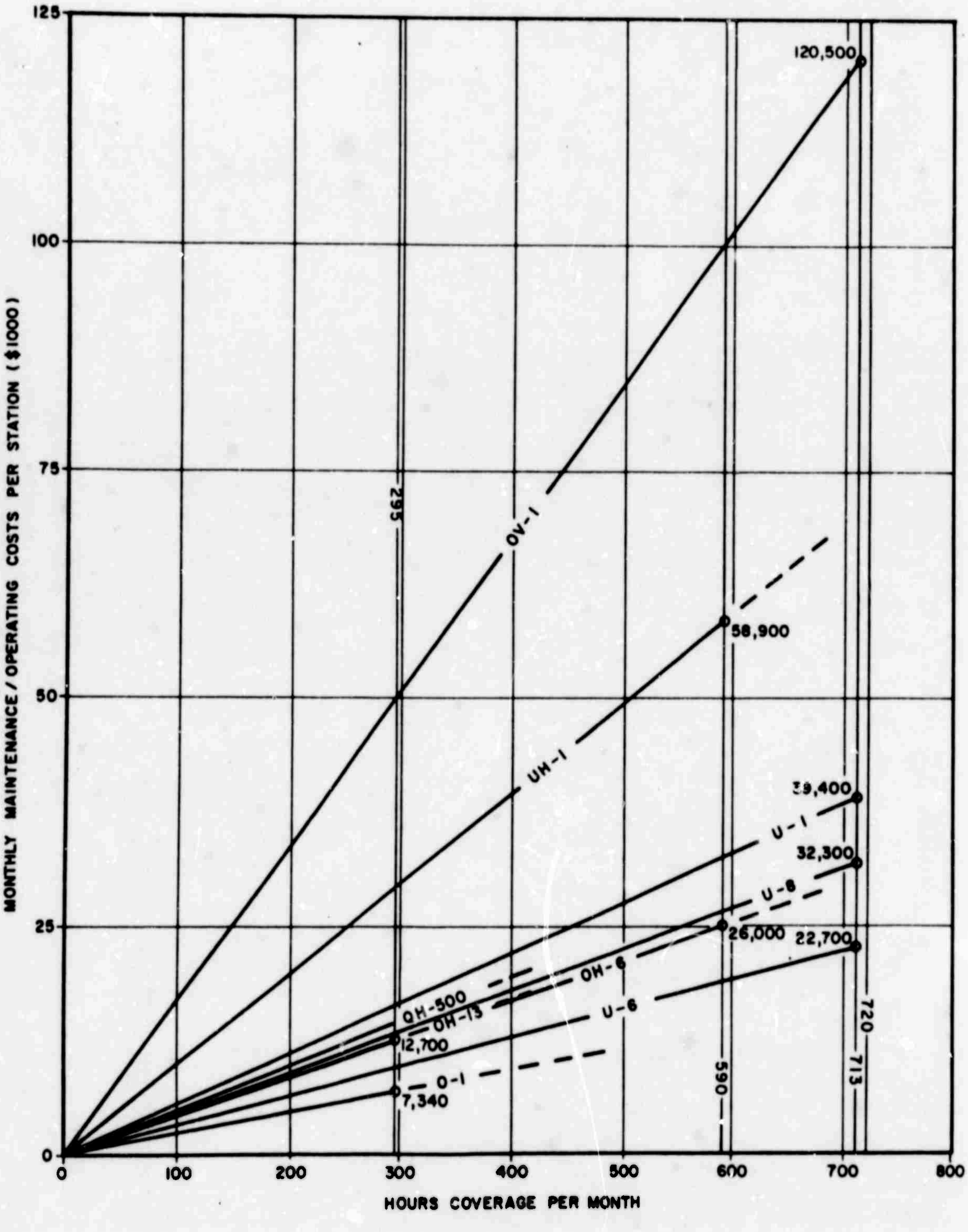


Figure 4-17. Maintenance and Operating Costs for One Station

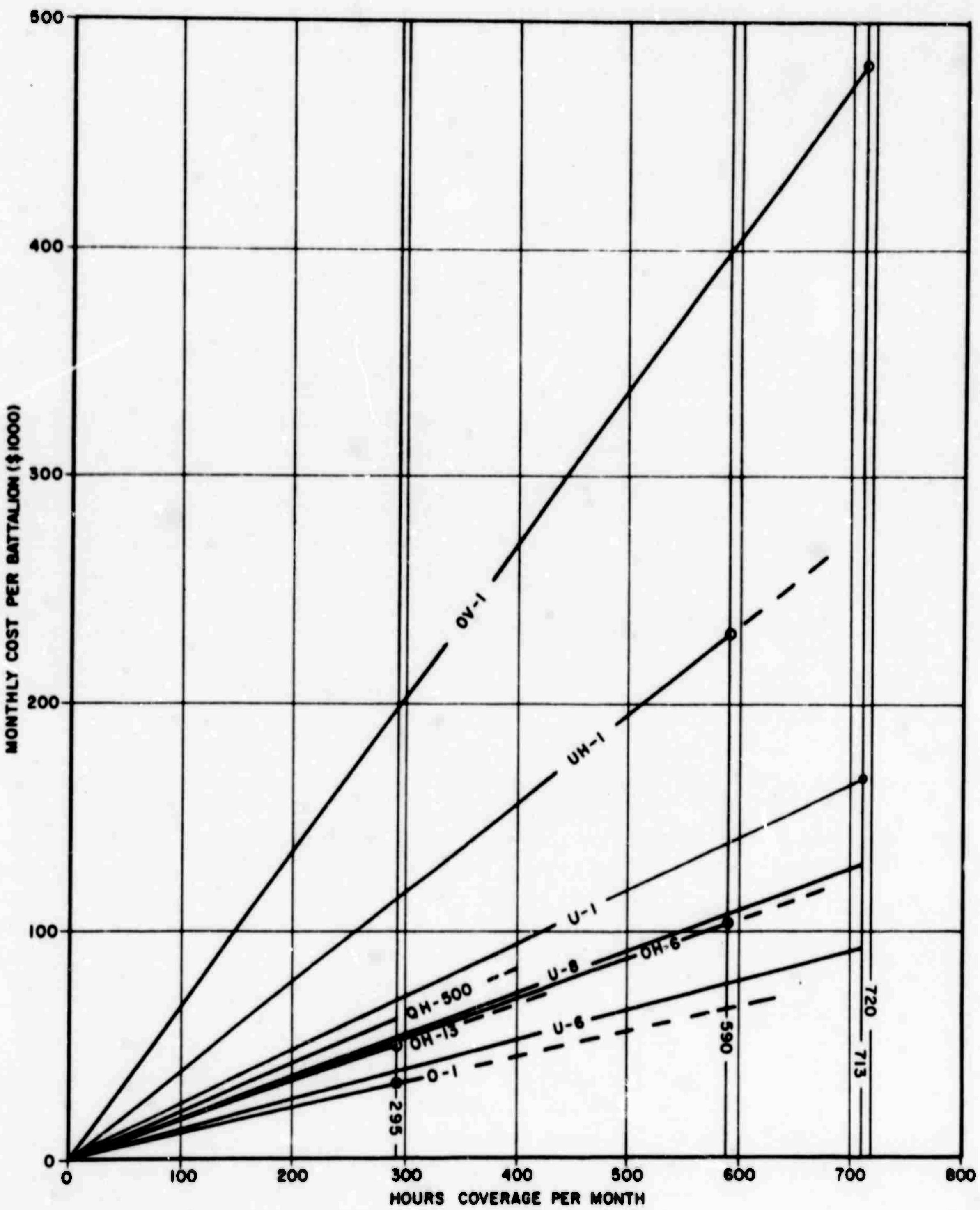


Figure 4-18. Maintenance and Operating Costs Per Battalion (Case 4 - 4 Stations)

Figure 4-17 lists the results for one station while Figure 4-18 lists the results for the four-station Case 4 battalion. Again, under the linear assumptions, the relationship between the two figures is such that the scales are changed.

4.5.6 Measure of Effectiveness. An equitable measure of effectiveness is difficult to find when dealing with such dissimilar platform candidates as balloons and manned and unmanned aircraft. It was decided to present representative candidates on a cost-per-channel-hour basis with each candidate used in optimum HARR fashion. Once a cost comparison could be made on this basis, qualifying statements would then be possible.

Figure 4-19 presents cost-per-channel-hour measure of effectiveness results for certain chosen representative candidates. Because of its sensitivity to payload, the tethered balloon shows up as a rather flat curve. Though the tethered balloon would have limited range in rugged terrain (i.e., unless tethered from a high peak), it looks very attractive for use for a small number of channels at the company level or for use at the company-to-battalion level when mutual frequency interference is not a problem.

The O-1E is also attractive on a cost basis for a small number of channels. However, it has limited "around-the-clock" utilization particularly in mountaineous topography. The O-1E Bird Dog would appear to be an excellent HARR platform choice when a command needs radio coverage of a few channels over a mobile area during daylight hours.

An aircraft that would be used in a fashion similar to the O-1E is the U-6A. It can carry a better payload than the O-1E and can be used at night over rough terrain. Since it is only more expensive to operate than the O-1E, it should be seriously considered as one of the candidate finalists.

The QH-50D DASH Helicopter has proven to be more disappointing as a HARR platform than was initially expected. Its relatively high attrition rate and ground support and control requirements added to the need of a special remote control channel switching system tend to put it in a less favorable light than its manned competitors. The two torpedoes now carried for its present mission would be removed for the HARR application, and additional fuel and the repeater package would be carried instead.

Probably the most promising candidate from the standpoint of channel flexibility and payload is the UH-1D. The advantages of this vehicle as a HARR platform are covered in the next subsection.

An indication of the applicability of a transport aircraft type to the HARR mission is given by the C-2V. It, of course, is the most expensive of the platforms to operate; but when used to carry a number of channels and control console, its cost per channel hour becomes quite reasonable.

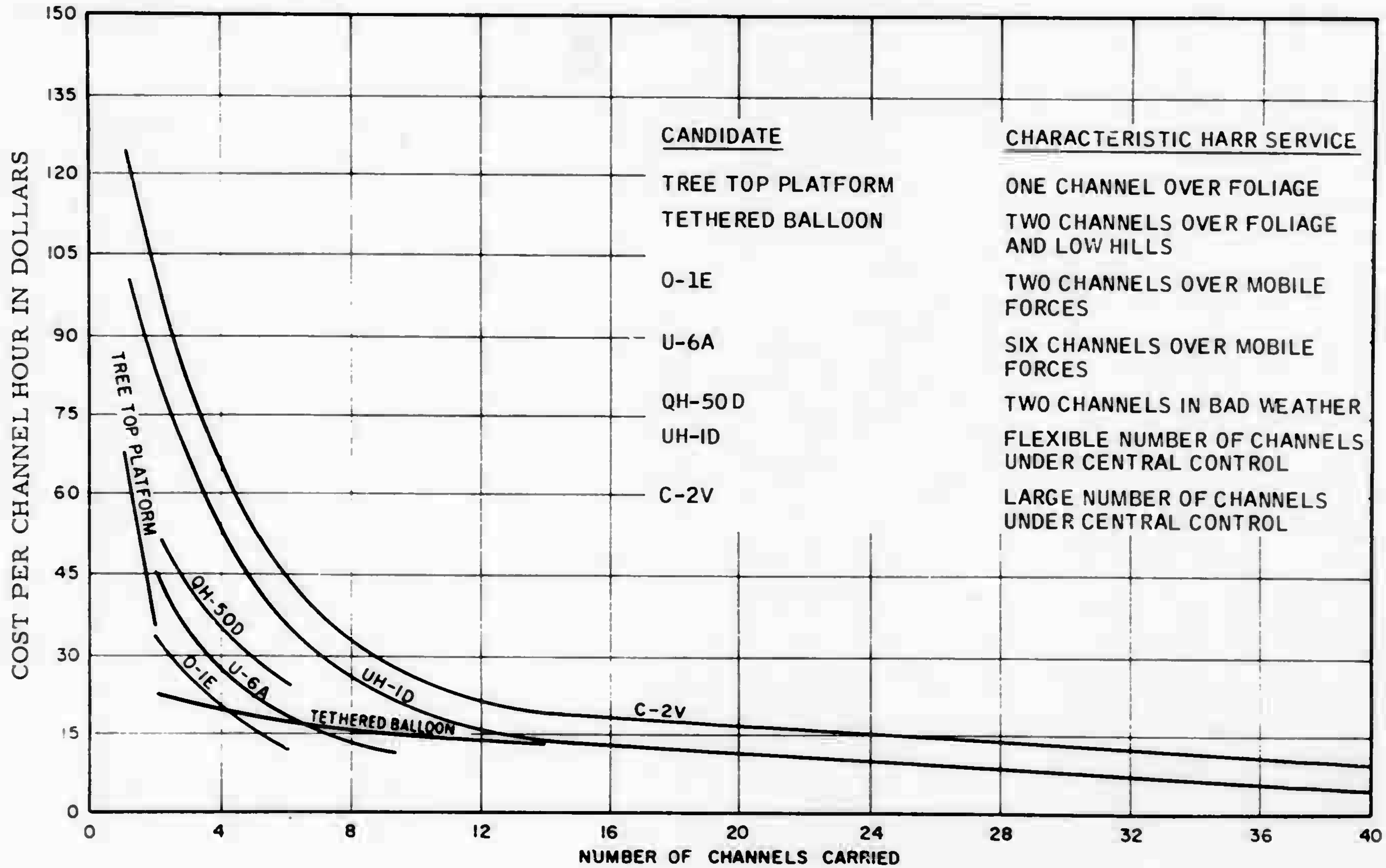


Figure 4-19. Platform Costs per Channel Hour for Representative Candidate Types

4.6 ANALYSIS OF PRIMARY CANDIDATES

4.6.1 Introduction. The preceding discussion has dealt with all categories of platforms applicable to the relay packages of Section 3 of this report. As has been indicated, manned aircraft are preferred from the viewpoints of technical feasibility and operational suitability. It is also evident that manned aircraft are costly in terms of normal acquisition and use, battlefield (remote aircraft conflict) operations, and battlefield penalties. Therefore, the HARR study has been concerned with parametric analysis of potential system approaches to the reduction of aircraft costs and the increase of operational effectiveness of aircraft for the HARR mission. Ensuing paragraphs deal with the following:

Time phasing
Costs
Initial aircraft candidates
Airborne functions
The UH-1D candidate

4.6.2 Time Phasing. The HARR study is concerned with "implementable" alternatives. The government has not specified deadline dates by which time a HARR operational capability must be in the hands of tactical commanders engaged in remote area conflict. Conversely, there is no indication that the HARR program should be continuingly concerned with striving toward an idealized system capability which is increasingly defined but not achieved at an appropriate time, after appropriate investment. Figure 4-20 represents a first iteration of the time phasing which may best match operational requirements, technological constraints, system costs and risk-taking.

The initial solution is defined as one applying current state-of-the-art to current combat requirements in Southeast Asia. Analysis to date indicates that the solution discussed in this report is also applicable, environmentally and command-wise, to other specific locales which have remote area conflict potentials defined in classified documents. As illustrated, a two-year service life for the initial solution is suggested to be a reasonable period for trade-off of battlefield penalties attributable to a less-than-perfect system, of amortization of developmental costs, and of learning curve experience applicable to follow-on system capabilities. This two-year period of system operation might be extended or reduced, depending on the intensity of combat requirements and the evaluated necessity for and achievability of follow-on solutions.

The interim solution is defined as modification of off-the-shelf equipment to meet existing or potential combat requirements. For this time-frame, operational planning and developmental activities may provide system flexibility to the degree that tactical commanders will employ a mix of aircraft and non-aircraft platforms for HARR missions, depending on requirements of the moment.

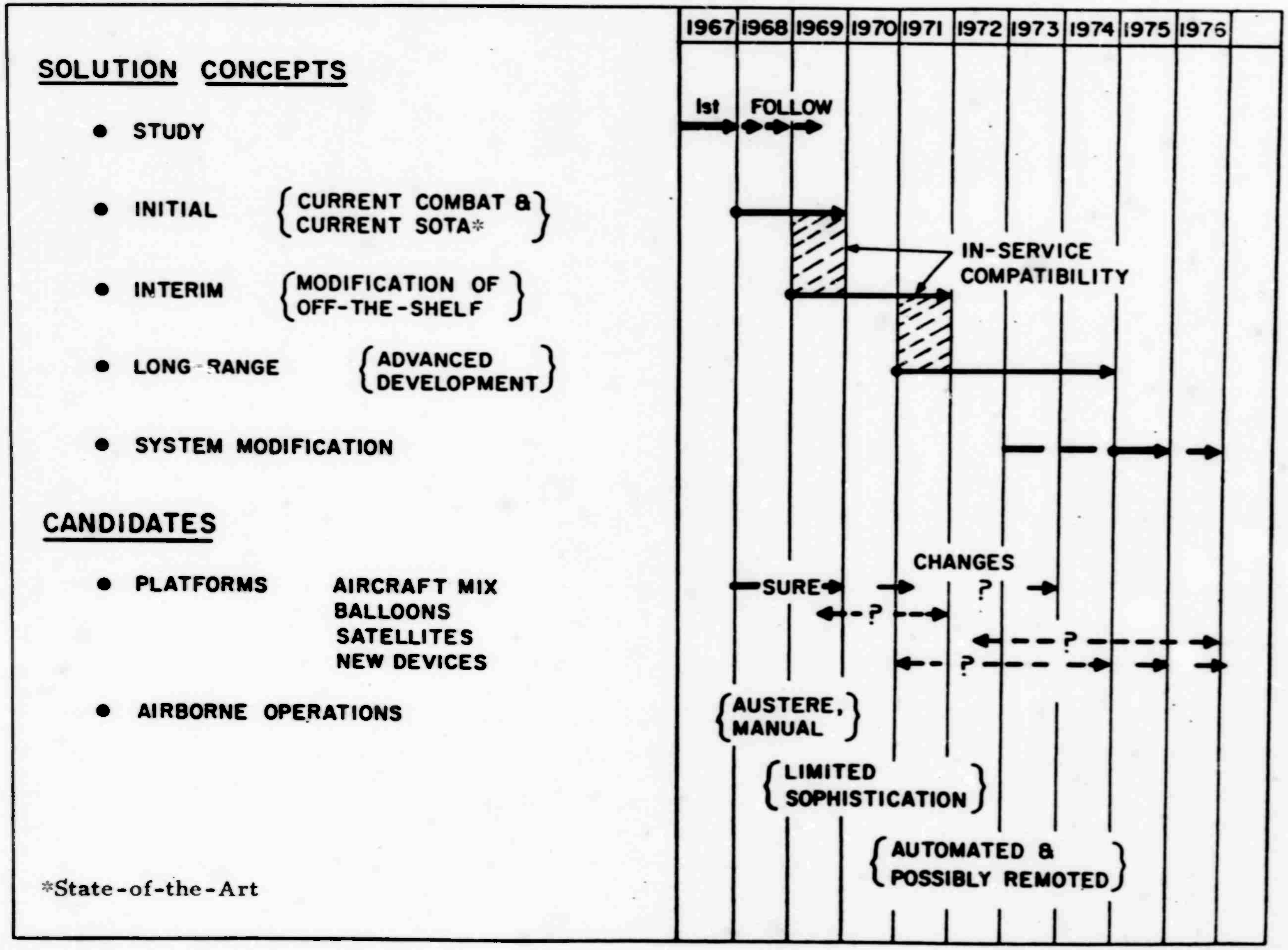


Figure 4-20. HARR Time - Phasing

A three-year operational life cycle is suggested. In this period, the locale of remote area conflict might be significantly different from the tropical environment specified for the present HARR study. Platforms conceivably would be required above windy deserts of large expanse, over a terrain consistently well above sea level, and in an envelope of persistently cold weather with large humidity variations.

The long-range solution is suggested to be one requiring a substantial investment in advanced development. Depending on progress made in the interim solution with relay packages, this development may be largely for new platforms representing radical departure from and/or significant improvement over those used previously for the HARR mission. A four-year life cycle also is shown. Also illustrated is the likelihood that no system will be ideal, hence a system modification during use of the long-range solution is shown. Figure 4-20 also suggests that the evolving of HARR systems must provide for "in-service compatibility" so that technological advantages afforded tactical commanders are not out-weighed by the burdens of complex, duplicative and dissimilar systems. For the initial solution applied to current combat requirements, the tactical ground subscribers and commanders should operate as at present; system changes should be platform/relay oriented, not impositions on ground operations.

Figure 4-20 also shows time phasing considered appropriate for major HARR platform categories for which parametric analyses are required contractually. Various experiments and combat expediencies have shown that aircraft can be used (and are being used) for radio relay. For an initial solution, the preferability of manned aircraft is attributable primarily to the algorithm that "range extension generates mutual interference." Because of this interference, manned control of channel switching and network operations is imperative. This circumstance has been discussed in Section 2 and also is reflected in paragraph 4. 6. 4 of this Section.

The basic question is, "Can airborne operations required for the HARR mission be automatic and/or ground-controlled, without airborne human intervention and judgment?" If the answer is yes, the parametric values are based on the following: how soon; at how much development cost; with what risk taking; with what battlefield costs and penalties; and for what gain in operational effectiveness. The present conclusion is that costs outweigh operational effectiveness for an "initial solution" predicated solely on an unmanned platform. Consequently, the role of unmanned platforms should be for emergency launching of limited relay frequencies and during limited operational periods, if at all.

As illustrated in Figure 4-20, it is suggested that the initial HARR airborne operation be comprised of austere, manual functions; the interim solution be comprised of limited sophistication of the functions found necessary/desirable during operation of the initial system; and the long-range solution may possibly be automated. In this way, the transition to unmanned alternatives can be at reasonable cost, with acceptable risk-taking, and for the operational effectiveness dictated by operational experience.

4.6.3 Costs. Components of the platform cost model are discussed in paragraph 4.5.4.2.1. It is self-evident that additional system costs are not measurable in dollars but are a function of tactical situations and decisions. Examples of such costs are:

a. reduced force mobility
b. increase logistics burdens
c. additional combat skill requirements

Figure 4-21 postulates system costs generally applicable to the Vietnamese conflict. The intent of this figure is to illustrate cost relationships which are pertinent to selection of HARR candidate systems and to evaluation of system parameters.

A basic design goal is to improve the quality of service afforded by a HARR system and to reduce HARR costs over a long-term program. The proposed measure is "cost per message relayed" which might be \$4.00 initially, and \$1.00 in a long-range solution. As illustrated, total operating costs may be quite high; and relatively large developmental investments may be justified by the combined need to reduce operating costs and improve service. The illustrated approximations indicate that HARR system costs are influenced more by the selection and tactical use of the platforms than by the selection and tactical use of relay packages.

Some bases for certain of the approximations used in Figure 4-21 are as follows:

a. "Cost per message relayed" is predicated upon tables of organization and equipment for standard forces and upon estimates of the number of transceivers in daily use by American, allied and indigenous forces. The need for range extension is a function of interplay between the environment and tactical situation. Assume that there are 5,000 transceivers assigned to forces which may require HARR support, that at any one time 50% of these transceivers do require HARR support, and that each of these transceivers averages six imperative messages daily. Then, the number of messages annually relayed approximates 5,000,000; the cost approximates \$4.00. The value of the message relayed can only be conjectured.

b. Annual platform operating costs are predicated on the example stated in paragraph 4.5.4.3.2 concerning complete and continuous coverage over the Vietnamese Corps III area, where terrain line-of-sight is a severe path problem. The tactical situation may not require "25 stations for 24 hours daily and 365 days yearly." Similarly, it may be a tactical decision to use a \$300-per-hour platform rather than a \$100-per-hour platform. The total costs illustrated are considered a realistic product of tactical requirements and actual costs. Obviously, the HARR study seeks a minimum number of

INITIAL OPERATIONS

	UNIT COST	ANNUAL COST
• PLATFORM	\$100 PER HR. ON STA	\$15,000,000 TO \$25,000,000
• RELAY	\$25,000 PER PLATFORM	500,000 1,500,000

LONG-RANGE DEVELOPMENT

	TOTAL	ANNUAL AMORTIZATION
• PLATFORM {MODIFY TEST}	\$2,000,000 TO \$4,000,000	\$ 500,000 TO \$ 1,000,000
• RELAY {RESEARCH DESIGN}	\$3,000,000 5,000,000	500,000 TO 1,000,000

OPERATIONS

	CHANGE FROM INITIAL	ANNUAL COST
• PLATFORM	FEWER; CHEAPER	\$ 3,000,000 TO \$ 5,000,000
• RELAY	IMPROVED SERVICE	1,000,000 TO 2,000,000
• TOTAL, INCL. DEVELOPMENT		6,000,000 TO 8,000,000

COST PER MESSAGE RELAYED

INITIALLY: \$ 4.00

GOAL: \$ 1.00

Figure 4-21. Postulated HARR Costs

platforms and minimum cost per platform commensurate with effectiveness required. It is not within the scope of the present HARR study to estimate how and to what degree tactical commanders will decide to employ HARR alternatives at their disposal.

4.6.4 Initial Aircraft Candidates. The ensuing discussion in the following paragraphs concerns the specific aircraft which presently are recommended as initial solutions to the HARR platform problem. Emphasis is placed on cost-effectiveness related to operational suitability as well as technical feasibility. The discussion is outlined as follows:

Basic considerations
Payload considerations
Performance values
Environmental values
Cost values
Platoon repeater platforms
Battalion repeater platforms
Division repe er platforms
Rotary-wing latforms
Drone platforms
Fixed-wing platforms

4.6.4.1 Basic Considerations. The HARR mission is similar in several significant respects to other airborne missions sponsored by Project Agile and presently used or programmed for the remote area conflict in Viet Nam. These missions include defoliation, reconnaissance and surveillance, specialized target acquisition, psychological warfare, specialized logistics support, and so on. It is predictable that similar missions would be required in the event of other remote conflict in the CINCPAC responsibility area, as well as CINCSOUTH, CINCSTRIKE, and other Unified Command areas. Airborne system commonalities include the following.

a. Aircraft require good loitering capability, i.e., the ability to stay over a confined ground area for a prolonged period, and a good ratio of "on-station time" to "to/from-station time."

b. Aircraft must be able to provide maximum "flying hours per month" in spite of environmental, logistics and personnel limitations.

c. Aircraft must be able to adjust well to unavoidable changes in mission profile while in flight.

d. Aircraft should have a good ratio of payload to operating costs, largely because of logistics austerity in remote area conflict.

e. Aircraft payload should not include costly self-protection features (e.g., high-speed performance, armor and armament, countermeasures, etc.), since air superiority is considered to be assured, and ground fire is the major threat.

In these and similar considerations, the prerogatives of the tactical commander to make battlefield selection of valid alternatives are of paramount importance. For HARR, there is no argument in favor of one aircraft to the exclusion of all others. Therefore, a command option to use one aircraft or another (from an inventory of several types/models/series) is recommended. This recommendation leads to the further recommendation that aircraft may be readily configured to and from the HARR mission, and therefore be available for other missions.

It also is basic that the aircraft selected for HARR either be in common usage for remote area conflict, or can be adapted easily in terms of operability, logistics support, command relationships, skill requirements, etc. In this respect, it is desirable to develop military technology which may be used increasingly by indigenous forces, with decreasing dependence upon American operation.

Another basic consideration is the need for platform maneuverability. This need is in two respects. First, it is important that the HARR platform, when airborne, can be quickly and reliably relocated to avoid terrain and weather, to avoid other airborne vehicles which may be hazardous, to remove itself as a hazard to other air operations, to avoid unusual hazards from the ground, etc. Secondly, it is important that the HARR platform be located to optimize the performance of its relay payload. Since battlefield tactical radio traffic rates, location of transceivers, environmental conditions, and communication ranges required or achievable cannot be predetermined or accurately predicted, it is desirable that the controlled, variable location of the HARR platform compensate adequately for the uncontrollability of the variables mentioned. In fact, it is also desirable to provide some degree of flexibility in HARR mission while the platform is airborne.

4.6.4.2 Payload Considerations. The HARR platform is required to accommodate the communications requirements and mission models discussed in Section 2. Likewise, the platform is required to carry the relay payload discussed in Section 3. Neither of these considerations is expected to be definitized to the point that a platform can be selected, tailored, or designed to meet a precise requirement. Rather, the total nature of remote area conflict is considered to be so volatile that the HARR mission must be served by a flexible, modular and modifiable system configuration. For convenience of expression, three basic "models" are discussed with respect to the HARR payload and platform. They are:

2-channel platoon repeater

8-channel battalion repeater

64-channel division repeater

In addition to the basic relay packages represented by these three payload models, there is variability in payload achievable by alternatives in aircraft manning, modification of basic aircraft configuration (e.g., fuel, armor, avionics), and selection of non-relay equipment for the HARR platform (e.g., auxiliary power unit, terrain avoidance radar).

Section 3 gives estimates of the physical characteristics of various relay packages which might be used for the HARR mission. In the selection of appropriate platforms, weight is the limiting physical characteristic. The platoon, battalion and division repeaters are expected to weigh 75, 215, and 1,500 pounds, respectively.

4.6.4.3 Performance Values. For any HARR platform, the primary value is on-station performance, that is, the ability to acquire and maintain the airborne position which optimizes the performance of the HARR system.

For flat jungle, a relay altitude of less than 2,000 feet above terrain will provide relay coverage 50 miles in diameter. On the other hand, a similar coverage in the mountainous terrain by a ground-air-ground link (as compared to a ground-air-air-ground link) would require platform altitudes of approximately 20,000 feet above the terrain, depending on the terrain. For lighter and less costly aircraft carrying heavier relay payloads, this high altitude reduces on-station endurance times sharply, due to high fuel consumption in attaining and maintaining altitude. Depending on topography and flight conditions, more than a half hour might be required to reach a 20,000-foot station from a take-off site ideally located.

There appears to be no way to position a platform at an altitude which will provide with any precision the relay coverage desired. Too low an altitude might provide significant gaps in the relay of communications between netted transceivers irregularly dispersed over irregular terrain. Too high an altitude might amplify the mutual interference which accompanies range extension when frequency assignments are shared between nets. At any altitude, both gaps and interferences might exist, with either predominating. The most desired performance value, then, is ability to change altitude quickly to achieve by performance monitoring, the altitude which best fits the relay mission in process. Environmental conditions and channel interference are likely to limit the achievability of this fit.

Since desired maximum and minimum platform altitudes are not readily defined in terms of relay performance, a generally applicable operational altitude is recommended as follows. The normal minimum altitude for a platform will be 3,000 feet above the terrain. At lower altitudes, the HARR platform is vulnerable to ground fire. Lower altitudes than 3,000 feet may be flown when the weather inhibits both hostile ground fire and attainment of higher altitudes, or when reduction in mutual interference for relay of messages which have urgent priority is mandatory. The normal maximum altitude for a platform will be 10,000 feet above the terrain. At higher altitudes, the HARR platform experiences higher cost, reduced endurance and potential conflict with other military traffic or (at still higher altitudes) commercial traffic. Higher altitudes than 10,000 feet may be flown to escape poor weather or to provide essential radio relay for operations in the highest mountains. Air-to-air relay should be employed to avoid sustained altitudes in excess of 10,000 feet. The HARR mission should be flown at as low an altitude as the requirements permit. Requirement to increase altitude to overcome terrain masking should be determined by relay test messages.

Path analyses referenced in Section 3 indicate that horizontal deviations from an ideal platform position have limited effect on path loss. A circular or lazy-8 mission profile of several miles width at 3,000-foot altitudes will not degrade or eliminate radio relay coverage significantly. In effect, a cone of coverage shifts with the platform's horizontal motion, and transmission loss is only at the perimeter of coverage. A random change in ground coverage will occur in horizontal platform shifting in mountainous terrain. Figure 4-15 illustrates this effect. In such terrain, relay test messages may be used to derive, while in flight, the flight pattern which minimizes terrain masking and maximizes radio relay service to ground transceivers most in need of the service.

4.6.4.4 Environmental Values. Values which bear most on selection of HARR platforms are weather and terrain. Effect of jungle foliage is largely with respect to difficulties in visual position-fixing. This effect does not vary particularly for the different loitering aircraft which are suitable HARR platforms.

Effect of weather on aircraft missions of the HARR sort in remote area conflict is extremely important. The HARR study team has not been able to acquire quantitative data on Vietnamese operations. News reports and government data on strike missions indicate that a surprisingly large percentage of strike missions are either aborted or diverted to secondary objectives because of weather. These sorties, of course, represent a traverse over greater distances and through more variable weather than anticipated on HARR missions. In the absence of conclusive evidence on weather pertinent to the HARR mission, the following experienced observations are paraphased.

a. "In the areas of conflict I was assigned to, there were very few days when the helicopters weren't flying at any hour of the day, regardless of the weather." (Told to the HARR study team by a senior Army officer.)

b. "Weather in Viet Nam is always bad. Throughout the seasons, a rule of thumb is that each day sees good weather in the eastern portion while it's bad in the western portion and vice versa." (Told by a retired Air Force officer who consulted on the HARR project and was previously in charge of Forward Air Controller functions throughout Viet Nam.

c. "The flyability of aircraft in bad weather is at the discretion of commanders at air strips. Under identical circumstances, one commander might ground all rotary-wing aircraft and allow most fixed-wing aircraft to fly, while another commander might decide exactly the opposite." (Same source as b.)

For the HARR mission, take-off, flight, and landing generally will be confined to a small geographical area under localized control It is suggested that the commander should have available locally a variety of platforms for the HARR mission, hence there would be a variable solution to weather problems. It is further suggested that a remotely based platform which can fly "over the weather and terrain" may be useful for HARR missions under unfavorable conditions, even though responsiveness to emergency relay requirements will be slower. For a classified airborne mission in Viet Nam--one similar in profile to the HARR mission--it has been decided through combat experience that weather avoidance radar must be installed. This decision for HARR would put the payload and pilot burden near maximum for the lighter HARR aircraft.

A correspondingly complex factor is terrain. Much of the limiting of missions resulting from unfavorable weather (as just discussed) also results from terrain. The two factors are obviously interrelated and have compound effects. The necessity for night flights for the HARR missions adds to these effects. One Army aviation specialist who was consulted by the HARR study team recommended against single-engine fixed-wing aircraft, and suggested twin-engine aircraft for higher altitudes, more difficult terrain, longer endurance and adverse weather conditions. He also suggested a mixed inventory of rotary and fixed-wing aircraft for the HARR mission.

A special environmental situation is the need for HARR missions within valleys so confined by high mountains that aircraft are operationally limited to the valley environment, with only occasional entrance and egress beyond mountain boundaries, and this during favorable weather. In this environment, single-engine aircraft have been able to operate within narrow corridors which are unavailable to twin-engine aircraft. Also, the few air strips available in such terrain very often can accommodate only the lightest aircraft. It is understood that a number of aircraft projects for remote area missions similar to HARR (i.e., all-weather, all-terrain, all-hours, varying altitudes, loitering, etc.) will carry terrain avoidance radar. These projects involve heavier aircraft than those suggested for HARR. Nevertheless, it now seems desirable to include this radar in HARR aircraft which carry the larger relay payloads and may be diverted in flight to difficult terrain, even if the relay payload must be reduced by a number of channels.

4.6.4.5 Cost Values. Figure 4-22 shows the aircraft which have been selected for initial HARR solution. Preceding discussion has dealt with some aspects of the columnar values shown for each aircraft, and more analysis is

	PLATFORM	FLIGHT HOURS	COST PER HR	MAX ALT.*	WORST TERRAIN	WORST WEATHER	PROBABLE BASE
2-CHANNEL PLATOON REPEATER	1 UH-ID HUEY	6	$120	15K'	MTN	FAIR	NEAR
	2 U-6 BEAVER	5	90	10	HILL	FAIR	CAMP
	3 O-1 BIRD-DOG	4	80	10	HILL	FAIR	CAMP
	4 DASH	8	150	15	MTN	BAD	CAMP
8-CHANNEL BATTALION REPEATER	1 LOH-6	3	120	10	HILL	FAIR	NEAR
	2 U-6	4	100	10	HILL	FAIR	CAMP
	3 UH-ID	5	140	15	MTN	FAIR	NEAR
	4 CV-2	6	210	20	MTN	BAD	CAMP
	5 C-123	7	230	25	MTN	BAD	REMOTE
64-CHANNEL DIVISION REPEATER	1 UH-ID	4	160	15	MTN	FAIR	NEAR
	2 CV-2	6	220	20	MTN	BAD	CAMP
	3 C-123	7	240	25	MTN	BAD	REMOTE

* 3K' MINIMUM OVER TERRAIN

Figure 4-22. Initial HARR Candidates

needed for these values and for cost values applicable to the aircraft selected. Some general observations are in order.

a. The most significant cost variation is expressable in "dollars per channel hour available" which varies between a maximum of $75 for the DASH carrying 2 channels to less than $3 for the UH-1D carrying 64 channels. It appears most desirable to use the fully loaded UH-1D whenever possible, and to avoid using the DASH when alternatives exist. As discussed elsewhere, the cost savings reflected in the largest configuration must be accompanied by a satisfactory solution to large-scale interference problems.

b. As best illustrated by the UH-1D, cost per flying hour increases in proportion to payload for any one aircraft. The altitude and endurance attainable decrease as payload increases. The cost per flying hour increases with altitude. A consistent reduction in flight hours attained increases the proportional fixed costs (e.g., base facilities) and therefore the cost per flying hour. Remote basing of aircraft reduces the on-station flight portion and the productiveness of flight hours.

c. Fine-grained analyses of these detailed cost inter-relationships are not in order for the HARR project at this time, since major cost/operational effectiveness trade-offs outweigh such considerations. For example, during a shortage of aviation gas for all missions, the tactical commander is likely to keep HARR missions at a minimum, and also likely to select the aircraft which consumes least gas per hour, even though resulting deficiences in endurance, altitude and coverage may result. His preference might be the O-1 Bird Dog, which can fly at 8 gallons per hour.

4.6.4.6 Platoon Repeater Platforms. As illustrated by Figure 4-22, the UH-1D "Huey" helicopter, U-6 "Beaver" single-engine utility aircraft, O-1 "Bird Dog" single-engine observation aircraft, and QM-50D DASH drone helicopter (designed for antisubmarine warfare) are recommended in that order.

The platoon configuration--so named for convenience only--is to satisfy several of the radio relay and range extension requirements discussed in Section 2. One requirement is to support platoons with limited dispersion throughout dense jungle and/or mountainous terrain, engaged in operations which may involve high-priority and high-density communications traffic. For this requirement, the tactical commander is expected to exercise the option of launching a HARR platform to cover reliably a specified (and relatively small) ground area for mission durations which may vary from one hour to six or more hours. Adverse weather and diurnal operations may be expected. In the event that coverage proves to be available from so-called battalion and division repeaters, the commander may call back the platoon repeater after very brief on-station time. For this mission, desired platform characteristics include low flying-hour costs, austere takeoff and landing capabilities, limited logistics support requirements, and quick responsiveness to tactical situations. Platforms with payload should be airborne within 15 minutes of the commander's decision and be on-station in less than a half hour under extreme emergency. For planned relay coverage, system costs are reduced by allowing two to three hours to achieve on-station coverage. The selected aircraft meet the foregoing specifications.

A second requirement to be satisfied by the platoon repeater is support of various units on nets which may be so widely dispersed that the commander responsible for these forces cannot determine in advance whether or not relay support will be needed. Therefore, HARR platform launchings must be planned well in advance, so that proper on-station positioning can be achieved initially. Maximum mission durations are desired, as are minimum costs. The communication path difficulties for this HARR mission are expected to be more associated with terrain than with foliage; therefore, aircraft probably will have to fly at higher altitudes and will have to maneuver to find optimum positioning for line-of-sight relay paths. The U-6 and O-1 aircraft, operated from base camp air strips, may be preferable to the UH-1D operated from helicopter clearings. The DASH is least preferred, under normal conditions, for this wide-dispersion mission as well as for the limited-dispersion platoon mission, because of the logistics and control burdens imposed on mobile forces. Its value is for emergency requirements to be met in spite of adverse environments, thus justifying higher attrition rates and more complex battlefield burdens.

4.6.4.7 Battalion Repeater Platforms. As illustrated by Figure 4-22, the preferred platform is the LOH-6 light observation helicopter. Its candidacy is strengthened by the fact that it is planned to replace, in large quantity, many of the light fixed-wing and rotary wing aircraft presently used in remote area conflict. In addition to the advantages accruing from prevalence (e.g., logistics support, inventory of skilled personnel, knowledge of flight parameters, full complement of support avionics), the LOH-6 has the advantage of being flyable from clearings closest to the desired area of radio relay coverage. Disadvantages of the LOH-6 may be in limited payload, endurance and altitude inter-relationships.

Other candidates for the battalion repeater mission are the U-6, the UH-1D, and CV-2 Caribou twin-engine aircraft, and the C-123 Provider (USAF) twin-engine aircraft, in that order.

The battalion repeater HARR mission is to satisfy radio relay and range extension requirements not too dissimilar from those specified above for the platoon repeater. Operationally, the battalion repeater supports more tactical organizations dispersed over a larger area for more continuous time periods. The HARR payload difference is only a matter of several hundred more pounds of relay packaging. The HARR platform selection and performance for the battalion mission involves more weight-carrying ability, more all-weather flying capability, and more maneuverability over difficult terrain.

These criteria rule out the O-1 and DASH, which were selected for the platoon mission. The LOH-6 and U-6 are acceptable only for the minimum battalion mission. The UH-1D is ideally suited for all battalion missions. The CV-2 and C-123 are expensive platforms, with slower response times, for the minimum battalion mission. They are more suited to a HARR mission supporting multiple battalions and additional special subscribers.

4.6.4.8 Division Repeater Platforms. In conventional ground warfare, the division is the maneuver element which exercises complete control over a continuous area, within which the classical function is to "move, shoot and communicate." In guerrilla and counter-insurgency operations within the limited warfare conducted in remote areas, any large ground area is likely to contain a heterogeneous population of hostile and friendly forces. The latter may be indigenous, American and allied, with variable organization and command relationships. Even so, it is the division command which, in remote area conflict, is likely to have the composite knowledge of all or most operations potentially requiring tactical radio relay, the generalized knowledge of existing and planned transceiver locations, the authority for assigning radio frequencies to specified organizations, and the control over use of HARR to extend range. It is therefore desirable to have a single HARR platform, dispatched from division headquarters, which can carry enough channels in its relay package to satisfy most (if not all) radio relay requirements throughout the division area of responsibility.

The scope and nature of division radio traffic have been discussed in Section 2.

The needs of a division for radio range extension are for highly mobile VHF transceivers in the forward area, and for semi-fixed transceivers (VHF frequencies and higher) in the rear areas.

As shown in Figure 4-22, the UH-1D is the preferred division repeater platform. It accommodates the minimum relay payload nicely, but it has only limited flight capability for the maximum relay payload. The CV-2 and C-123 have capacity in excess of the maximum relay payload now estimated. They also have better ability for overcoming environmental constraints than does the UH-1D. Contrarily, the CV-2 and C-123, because of basing limitations, cannot reach the division's on-station relay status as quickly as the UH-1D.

It is suggested that the command decision might generally be to use the UH-1D when relay payload requirements are minimum, time allowable for reaching on-station is minimum, and the mission profile is for shorter duration and restricted positioning. Conversely, the CV-2 and C-123 might be used when payload requirements are maximum, several hours are allowable for reaching on-station, maximum HARR mission duration is desired, and the platform may be flown in a larger envelope (because of transceiver deployment, terrain and weather conditions, etc).

Additional platforms have been considered for the division repeater mission, and might in fact be used advantageously if they are available in the remote area and can be outfitted there for the HARR mission in addition to or instead of their primary missions. The Navy's S-2 and P-2 antisubmarine warfare aircraft are being recommissioned for remote area conflict use. As announced publicly, these aircraft have been selected for reconnaissance missions because of excellent loitering capability, good speed to the point of use, low acquisition costs, extensive operational experience and logistics support, favorable payload factors, etc. For the HARR mission, these characteristics have similar merit. Further evaluation involves military considerations, such as preempting of limited inventories, establishment of feasible command channels, and disposition of equipments and procedures not compatible with the HARR mission.

4.6.4.9 Rotary-Wing Platforms. As a group of aircraft, helicopters are advantageous for the HARR mission because of their ability to operate from nearby clearings rather than remote air strips. This advantage is partly offset by a higher fuel consumption rate which requires that a refueling complex be operated in very remote areas which are also accessible to other aircraft. Air strips in the rear echelons tend to accommodate most COIN-type aircraft, but forward airstrips often must be closed to most aircraft because of weather and correlated runway conditions.

Another advantage of helicopters for HARR is the ability to hold a very tight position over rugged terrain in bad weather. Hovering, per se, is not desired because of the very high fuel consumption involved. Very tight flight patterns are not required for effectiveness of HARR radio relay, except for extreme line-of-sight problems. The advantage lies in greater ability to avoid dangerous terrain at night and in bad weather at lower altitudes, thus reducing chances for non-combat loss of personnel, platform and payload.

Helicopters, more so than fixed-wing aircraft, degrade in performance characteristics and increase in operating costs as payload weights increase. This disadvantage can be compensated for somewhat by avoiding overloading and maximum altitudes for HARR mission. Analysis recommends against extensive use of helicopters larger than the UH-1D because of more unfavorable costs, as compared to fixed-wing aircraft. Lighter helicopters (possibly including the LOH-6) are less desirable because of poor performance/payload ratios and limited endurance of platform and pilot.

Operational experience also indicates that a number of the helicopters presently in use have not performed to specification, have presented excessive reliability and maintainability problems, and should be replaced by newer aircraft. The LOH-6 is planned to replace light helicopters and fixed-wing aircraft, but it is premature to place total confidence in the LOH-6. On the other hand, the UH-1D has surpassed performance expectations and is planned to be the predominant helicopter for many more years. The high level of logistics support and skilled personnel inventory for the UH-1D are additional reasons for the "Huey" being most preferable for the HARR mission.

4.6.4.10 Drone Platforms. For the HARR mission profile as defined by study to date, the QM-50D DASH drone is the only drone platform suggested. As shown in Figure 4-22, the DASH might be used in environmental circumstances which preclude manned aircraft, because of increased probabilities of non-combat loss. DASH costs per flight hour are high, but these costs may be tolerable for urgent radio relay requirements. The relatively high attrition anticipated for DASH on HARR missions also should be justified by urgent requirements. This attrition is not because of the helicopter's unworthiness, but rather because of the uncertainty of ground control at extended distances (e.g., 20 miles) in poor weather and difficult terrain. Because launch and recovery of the DASH is a large part of its battlefield burden, long endurance flights should be planned. The payload of the DASH on a HARR mission can be up to 800 pounds of fuel and relay equipment. With two relay channels, an 8-hour flight is achievable.

Fixed-wing drones have been rejected as HARR platform candidates. Operating costs, battlefield burdens and payload limitations for fixed-wing drones are as disadvantageous as for the DASH. Without development and testing, there is no assurance that external fuel stores of sufficient capacity for desired mission endurance can be added. The DASH, with its helicopter flight characteristics, presents no such aerodynamic problem.

Perhaps the most important reason for favoring a rotary-wing drone over a fixed-wing drone is the combined difference of speed/flight pattern. A fixed-wing drone flying a large pattern at relatively high speed might crash into terrain under expert control, while a DASH helicopter flown in a small pattern at low speed has a better chance for terrain avoidance, even if control is less expert. Should propagation and interference tests and "air corridor protection measures" permit drones flying high over rough terrain, fixed-wing drones may be reconsidered as HARR platforms.

As a HARR platform, the drone should be evaluated against other unmanned alternatives. The tethered balloon, with approximately the same payload capacity, is perhaps the best comparison. If cost is the primary concern, the balloon may be preferred to the DASH because of lower platform costs and lower attrition of the platform/relay configuration. However, if precise location and relocation are needed--particularly over rough terrain during high winds--the DASH has definite advantage over balloons. Both are hazardous to other air traffic. The DASH platform and the balloon proper can provide visual and radar illumination. Illumination should also be provided for the balloon tether which constitutes a hazard to low- level helicopter traffic.

Several classified field experiments and CONUS developmental activities have shown the feasibility of using DASH in remote area missions similar to HARR.

4.6.4.11 Fixed-Wing Platforms. In addition to the four shown in Figure 4-22 (O-1, U-6, CV-2 and C-123), the OV-1C and U-3 have proven operationally effective in loitering-type missions in Viet Nam. Both are light twin-engine aircraft which might be preferable to the O-1 and U-6 for missions of longer duration in more unfavorable environments. However, study does not show this to be necessarily the case. No fixed-wing aircraft other than the CV-2 and C-123 are suggested for the payload size called the division repeater. The CV-2 appears preferable to the C-123 because of its ability to use marginal air strips in marginal weather.

The CV-2 and C-123 have capacity in excess of that required for the maximum HARR mission payload suggested by analysis to date. There is a possibility of multi-mission flights (i.e., HARR and other missions requiring loitering over the same area) for these two aircraft, and channels for investigating this possibility might be a desirable step within the remote area conflict program.

The spare cargo space of the CV-2 and C-123 offer an advantage not found in the aircraft selected for the HARR mission. This advantage is the facility for the crew to recuperate from cramped quartering during mission lulls and by rotation. Smaller aircraft sometime have 20% or more endurance beyond that of the pilot. This difference is negligible on a single mission but very important in planning year-round operational capability. Experience in flying four-engine aircraft on barrier missions of 12 or 14 hours duration has shown the importance of human factors under the conditions which would pertain to continuous HARR operations.

4.6.5 Airborne Functions. The cost and operational effectiveness of various HARR platform/relay configuration are influenced significantly by the functions to be performed while airborne. The basic functions are the control of the platform and control of the relay equipment. The HARR project is concerned solely with the airborne relay of radio communications which have, otherwise, insufficient range.

Analysis has not shown any unmanned platform to be dependable or desirable for launching, positioning or carrying the various HARR payloads (at least not in the near future). The DASH drone helicopter is, at best, an emergency measure which involves some risk-taking that should be resolved by a thorough test program before commitment to an operational program or deployment in actual conflict.

Assuming that control of the platform is not to be remoted but is to be in the hands of the pilot, the next major question is, "Can or should the control of the relay equipment be remoted?" If not, it must be determined whether the relay control functions should be performed by the pilot or by another crew member. These determinations depend upon a definition of candidate control functions and upon a realistic appraisal of the cost and operational effectiveness of the functions.

Remoting of DASH control to a ground station is required for both platform and relay. For the platform, only a telemetry and command data link is required (this is already available, including an option to switch to a programmed flight profile). The same data link is usable for limited relay control, such as turning a channel on or off. Remote relay control responsive to evolving requirements of ground subscribers would call for, at a minimum, transmitting relayed radio traffic to the DASH control station where the operational inter-relationships of platform and relay functions would be dealt with in real time.

For a platform already manned, there is no cost/operational effectiveness basis for remoting control of the relay, since there is no need for continuous control on the ground instead of in the air and since all remoting costs would be redundant.

Accepting airborne, manned control of the HARR relay equipment, a trade-off is needed on the level of control required and the interface between airborne platform control and airborne relay control. These considerations vary with the size of the HARR repeater (i.e., platoon, battalion or division) and with the platforms selected for the three payload classes.

In the platform repeater class, the U-6 can be only a one-man aircraft. The O-1 normally carries an observer, but for the HARR mission this "200-pound payload" must be replaced by additional fuel and the relay package in proper balance. The UH-1D has a co-pilot and room for eleven combat-equipped troops. For HARR, only the UH-1D can support a "communicator" to manually control the relay equipment and to interface with "pilot" functions. The O-1 and U-6 pilots must not be given time-consuming additional duties, e.g., HARR relay control. This point is stressed by authorities on aircraft operations over Viet Nam and would apply equally to any other remote area conflict having similarly hostile environment.

In the battalion repeater class, the second man in the LOH-6 may necessarily be displaced by the HARR payload. If not, he should be repositioned so that he can act as "communicator," i. e., as controller of the relay equipment. The UH-1D, CV-2 and C-123 have ample space for manning the battalion class payload and also the division class payload, even if several communicators are required to control relay functions at maximum payload and maximum intensity of communications support.

4.6.6 The UH-1D Candidate. Earlier discussion within paragraph 4.6 has indicated the preferability of the UH-1D "Huey" for the HARR mission. Pertinent information is shown in Figure 4-23, "General Arrangement Diagram;" Table 4-17, "Principal Dimensions;" and Table 4-18, "Communications and Associated Electronic Equipment." Figure 4-24, "Conceptual UH-1D HARR Layout," is an approximation of how the personnel, equipment and functions discussed throughout paragraph 4.6 might be accommodated within the UH-1D for the "Division repeater" configuration.

Additional basic information about the UH-1D is listed as follows:

a. Model: The D model is larger than the UH-1B and UH-1C which have permanent gun and rocket racks installed externally and are used primarily as attack aircraft. The UH-1D mounts guns in the cargo area, but is used primarily for troop transport and medical evacuation.

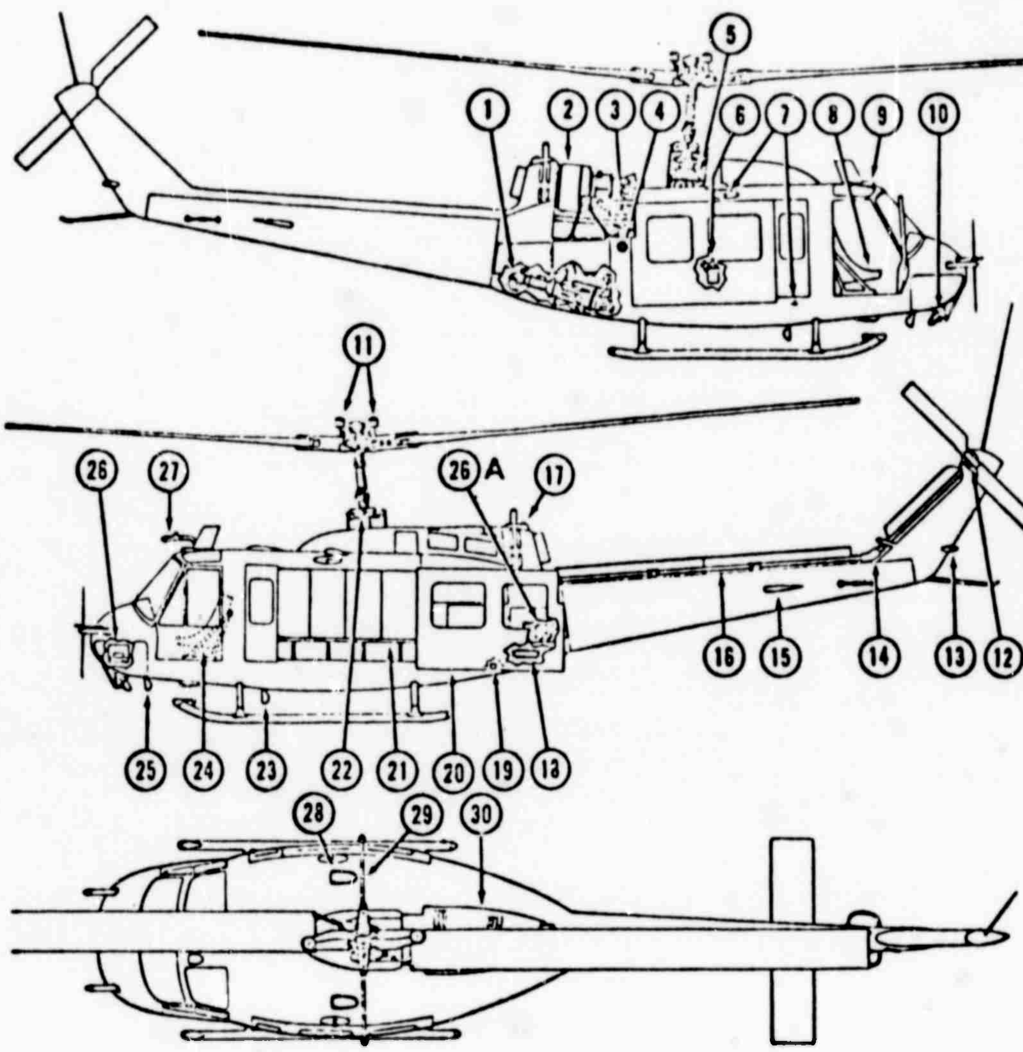
b. Inventories: Approximately 1,000 B's, fewer C's; almost 4,000 D's.

c. Service ceiling: 22,000 feet at intermediate gross weight; fuel flow increases rapidly above 16,000 feet.

d. Weights (pounds): Airframe 4800, fuel 1300, personnel 600, other 100, payload 2700, gross 9500. Auxiliary fuel 110.

e. Cost: $250,000 plus $90,000 avionics; 12-year life.

f. Machine guns: Each 130 pounds plus 80 pounds ammunition. Four are generally carried (delete or reduce for HARR missions).



1. Heating Burner and Blower Unit
2. Engine
3. Oil Tank Filler
4. Fuel Tank Filler
5. Transmission
6. Hydraulic Reservoir
7. Forward Navigation Lights (4)
8. Pilot's Station
9. Forward Cabin Ventilator (2)
10. Cargo Suspension Mirror
11. Collective Counterweights (44 Ft Rotor Only)
12. Tail Rotor (90°) Gear Box
13. Aft Navigation Light
14. Tail Rotor Intermediate (45°) Gear Box
15. Synchronized Elevator
16. Tail Rotor Drive Shaft
17. Anti-Collision Light
18. Oil Cooler
19. External Power Receptacle
20. Cargo-Passenger Door
21. Passenger Seats Installed
22. Swashplate Assembly
23. Landing Light
24. Copilot's Station
25. Search Light
26. Battery

26A. Alternate Battery Location (Armor Protection Kit)

27. Pitot Tube
28. Aft Cabin Ventilators (2)
29. Stabilizer Bar
30. Engine Cowling

Figure 4-23. UH-1D Helicopter General Arrangement Diagram

Table 4-17. UH-ID Principal Dimensions

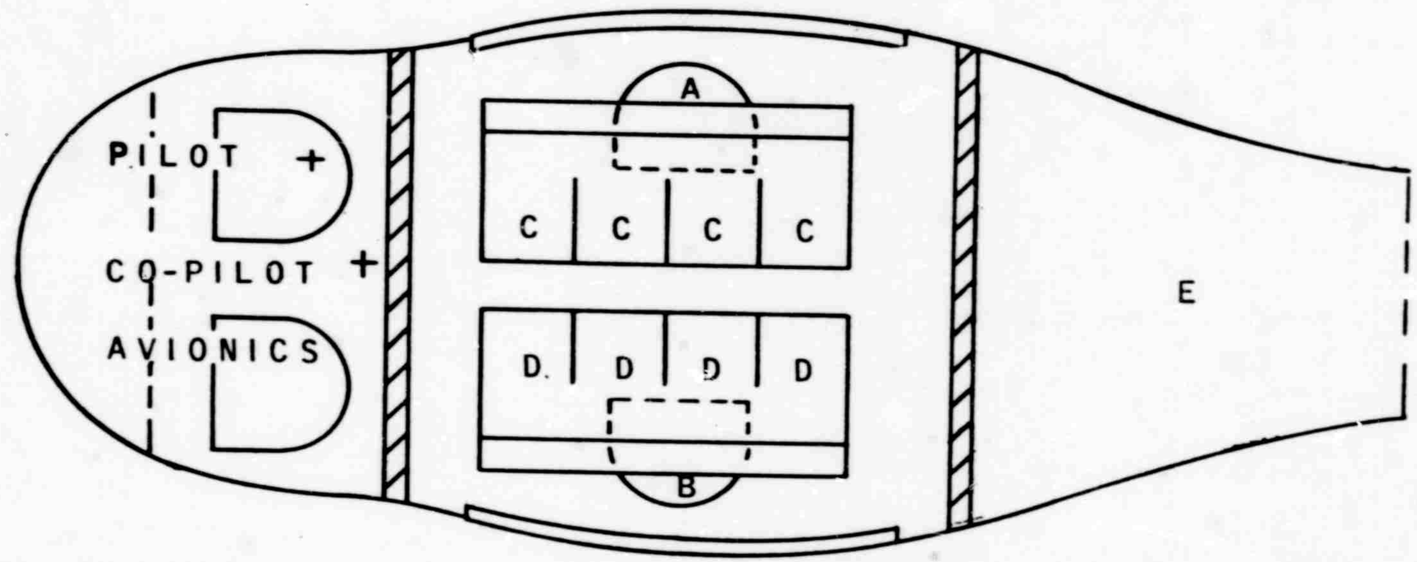
LENGTH:	44 FOOT ROTOR	48 FOOT ROTOR
Overall (main rotor fore and aft and tail rotor horizontal)	53 ft. 1.1 in.	57 ft. 1.1 in.
Overall (main rotor fore and aft and tail rotor vertical) to end of tail skid	50 ft. 2.35 in.	54 ft. 1.92 in.
Nose of cabin to aft end of vertical fin	39 ft. 5.09 in.	41 ft. 11.15 in.
Nose of cabin to aft end of tail rotor (rotor horizontal)	42 ft. 10.1 in.	44 ft. 10.1 in.
Nose of cabin to center line of main rotor	11 ft. 8.66 in.	11 ft. 8.66 in.
Skid gear	12 ft. 2.0 in.	12 ft. 2.0 in.
WIDTH:		
Synchronized elevator	9 ft. 4.3 in.	9 ft. 4.3 in.
Skid Gear	8 ft. 6.6 in.	8 ft. 6.6 in.
Stabilizer bar	9 ft. 0.4 in.	9 ft. 0.4 in.
HEIGHT: (To static ground line.)		
Tip of main rotor forward blade:		
Secured aft	17 ft. 2.5 in.	17 ft. 1.49 in.
Pressed down forward	7 ft. 7.0 in.	7 ft. 0.69 in.
Top tip of tail rotor vertical position	14 ft. 3.75 in.	14 ft. 8.20 in.
Top of stabilizer Chinese weights	13 ft. 4.0 in.	13 ft. 4.0 in.
Top of cabin	7 ft. 8.4 in.	7 ft. 8.4 in.
Bottom of cabin	1 ft. 3.0 in.	1 ft. 3.48 in.
Tail rotor clearance (ground to tip, rotor turning)	5 ft. 9.75 in.	5 ft. 11.5 in.
Tail skid to ground	4 ft. 5.0 in.	4 ft. 9.0 in.
DIAMETER (Swept circle):	4 ft. 5.0 in.	4 ft. 9.0 in.
Main rotor	44 ft. 3.2 in.	48 ft. 3.2 in.
Tail rotor	8 ft. 6.0 in.	8 ft. 6.0 in.
Stabilizer bar	9 ft. 0.4 in.	9 ft. 0.4 in.
Turning Radius		34 ft. 0.4 in.

Table 4-18. UD-1D Communications and Associated Electronic Equipment

FACILITY	NOMENCLATURE	USE	RANGE	LOCATION OF CONTROLS	REMARKS
UHF command communications	Radio Set AN/ARC-55B AN/ARC-51X or AN/ARC-51BX	Two-way voice communications in the frequency range of 225 to 399.9 mc	Line of sight	Pedestal	
FM liaison communications	Radio Set AN/ARC-44 or AN/ARC-54	Two-way voice communications in the frequency range of 24.0 to 51.9 mc	Line of sight or 50 miles average conditions	Pedestal	AN/ARC-44 dynamotor supplies power for operation of signal distribution panel SB-329-AR
Intercommunication	Radio Set SB-329/AR or C-1611A/AIC	Intercommunication between crew members	Stations within helicopter	Pedestal and cabin overhead	Press-to-talk switches located on cyclic sticks, foot switch on floor in cockpit area, and crew members control panel
VHF command communications	Radio Set AN/ARC-73	Two-way voice communications in the frequency range of 116.00 to 149.95 mc	Line of sight or 50 miles average conditions	Pedestal	The AN/ARC-73 is used as an alternate for the UHF Command Set
HF SSB/AM communications	Radio Set AN/ARC-102	Two-way voice communications in the frequency range of 2.0 to 29.999 mc		Pedestal	Minimum pilot weight is 260 pounds with AN/ARC-102 installed
VHF emergency transmitter	Transmitter T-366/ARC	VHF emergency transmitter	Line of sight		The VHF navigation receiver used in conjunction with T-366/ARC standby transmitter

Table 4-18. UD-1D Communications and Associated Electronic Equipment (Continued)

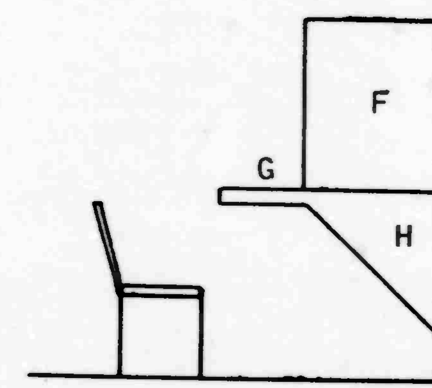
FACILITY	NOMENCLATURE	USE	RANGE	LOCATION OF CONTROLS	REMARKS
FM homing	Antenna Group AN/ARA-31 used with AN/ARC-44 or AN/ARA-56 used with AN/ARC-54	Homing on FM tranmission within frequency range of 24 to 49 mc	Line of sight or 50 miles average conditions	Pedestal	The FM liaison set must be operated while homing
VHF navigation (VOR, VAR, LOCALIZER)	Radio Receiver AN/ARN-30E or AN/ARN-82	VHF navigational aid and VHF audio reception in the frequency range of 108 to 126 mc	Line of sight	Pedestal	Information is presented aurally in headset, and visually on course indicator and bearing-heading indicators.
Automatic direction finding	Direction Finder Set AN/ARN-59 or AN/ARN-83	Radio range and broadcast reception; automatic direction finding and homing in the frequency range of 190 to 1750 kc	50 to 100 miles range signals 100 to 150 miles broadcast	Pedestal	
Magnetic heading Indications	J-2 Gyro Magnetic Compass	Navigational Aid		Instrument Panel	
Marker beacon reception	MB Receiver R-1041/ARN	Navigational Aid	Vertical to 5[illegible],[illegible]0 feet	Pedestal	
Identification	Transponder Set AN/APX-44	Transmits a specially coded reply to a ground-based IFF radar interrogator system	Line of sight		



CARGO COMPARTMENT:

7.7'L X 8.0'W X 4.1'H; 4.0'H X 6.2'W DOOR
LOADING: 300 LBS. PER SQ. FT.

A. COMMUNICATOR (EMERGENCY GUNNER)
B. COMMUNICATOR FOR MAX. MISSION
C. FOUR 8-CHANNEL REPEATER MODULES -- VHF
D. SAME AS C OR UHF AS NEEDED
E. LIMITED HARR EQUIPMENT -- E.G., AUXILIARY POWER UNIT
TERRAIN AVOIDANCE
WEATHER AVOIDANCE



F. STANDARD REPEATER RACKS
G. DISPLAY CONSOLE
H. BACK-WIRING, RECORDER, ETC.

Figure 4-24. Conceptual UH-1D HARR Layout

In summary, the referenced analyses indicate the preferability of the UH-1D as a HARR platform in terms of mission performance at all levels of support--platoon, battalion and division. The cost of the UH-1D is comparatively high for the platoon repeater, but favorable for the division repeater. The division repeater is preferred for the HARR mission. In the initial solution or early time-frame, the frequency interference problems associated with extension of radio range are to be overcome by improvisation techniques and evolutionary equipment modifications for the airborne HARR communicator. Subsequently, solution to interference problems may stem from more extensive development of HARR relay packages, e.g., the use of directive antennas.

In spite of miniaturization potentials for electronic equipments, the maximum HARR payload is expected to continue to require a platform of the UH-1D size, or larger. The HARR mission profile is expected to continue to require relatively precise location over a force area, particularly in difficult line-of-sight terrain. A more pressing requirement might be for maximum flyability and maneuverability under most difficult weather and terrain conditions, with nominal assistance from such ground support facilities as radar, prepared airfields, etc. The emerging "compound helicopter" appears to meet these broad specifications better than other aircraft in development. Prototype compound helicopters have already flown "loops" and other acrobatics, indicating an excellent airworthiness.

Combat evaluation of the AAFSS compound helicopter will not be completed before 1970, and no commitment to extensive procurement of this aircraft is in sight. Furthermore, the AAFSS could not be modified to accommodate the UH-1D's HARR payload quickly or inexpensively. A more promising activity is the proprietary (Lockheed) development of a Universal Tactical Transport (UTT). The UTT compound helicopter is proposed to satisfy a variety of limited warfare mission requirements of all military services. In every respect, it would be a natural and desirable "next generation" platform for accommodating the UH-1D's HARR payload.

SECTION 5

APPENDICES

5.1 RF CROSSTALK TESTS ON AN/PRC-25's

At Page Communications Engineers Laboratory in Falls Church, tests for radio frequency crosstalk between two PRC-25's were conducted in the laboratory and in the open air.

A single transmitting frequency, 33.05 MHz, was used for all the tests; the receiver frequency was varied and notation was made of those channels experiencing RF interference from the transmitter. Table 5-1 shows a summary of these tests. Tests 1 and 2 were conducted in the laboratory with a common power supply; Tests 3, 4, and 5 were conducted outside. Tests 3 and 4 used separate external batteries; Test 5 used the PRC-25 BA-386 battery. Tests 4 and 5 were identical except for the substitution of the BA-386 for the external batteries. It is interesting to note the difference between the number of unusable channels found with external batteries versus the number with internal batteries; this difference must be attributed to radiation from the external battery cables. Tests 6 and 7 were conducted with BA-386 batteries in the laboratory and were made to determine the effect of shielding on the AN/PRC-25 equipment. Test 6 was the control test; Test 7 was identical with Test 6 except that both AN/PRC-25 units, as well as the hand sets and all cables, were contained within aluminum foil ("Reynolds Wrap") which was grounded to the body of the transceiver at the base of the antenna. In this way, only the antenna protruded from an otherwise "RF-tight" unit. The improvement because of this shielding can be seen in Table 5-1.

Tests 3, 4, and 5 are a reasonable reproduction of relay conditions using external and internal power which will be experienced by troops in the field after the troubles of the Retransmission Cable have been corrected. In these tests, it was found that a grounding cable connecting the two units had negligible effect, bad or good, on the results.

The usability of the receiving channels was determined in accordance with the ability of the remote transmitter to operate the receiver squelch circuits. In a very small number of cases, RF crosstalk was found on channels where the squelch of the receiver did not operate. That the transmitting PRC-25 was, in

Table 5-1. RF Cross-Talk Results on AN/PRC - 25's

In These Frequency Ranges (MHz)	This Number of Unusable Channels Were Found							Number of Unusable Channels From Chart
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6 Unshielded	Test 7 Shielded	
30-31	0	2	2	4	2	2	4	2
31-32	6	6	4	10	0	7	5	1
32-33	5	8	7	7	4	8	10	1
33-34	1	7	4	12	5	17	16	2
34-35	2	5	3	8	7	6	7	0
35-36	1	4	3	12	13	15	5	1
36-37	1	6	2	10	13	18	3	1
37-38	1	0	0	6	11	14	1	2
38-39	1	0	0	6	12	4	0	0
39-40	1	1	0	1	6	1	0	0
40-41	1	1	0	8	11	1	0	1
41-42	0	1	0	7	4	0	0	0
42-43	0	3	4	10	4	1	0	0
43-44	3	4	2	13	12	1	2	0
44-45	4	6	4	15	12	1	2	2
45-46	0	2	2	17	—	2	0	1
46-47	0	3	3	15	—	1	0	0
47-48	0	3	2	19	—	1	0	0
48-49	1	3	2	20	—	0	0	0
49-50	2	1	0	19	18	0	0	0
50-51	0	0	0	17	14	2	0	0
51-52	0	0	0	—	—	—	—	0
52-53	0	1	1	—	—	—	—	0
Separation	4'	10'	20'	20'	20'	10'	10'	
Antenna Size	3'	10'	10'	10'	10'	3'	3'	
Location	LAB	LAB	OUTSIDE	OUTSIDE	OUTSIDE	LAB	LAB	
Polarization	HOR	HOR	VERT	VERT	VERT	VERT	VERT	
Power Source	LAB SUPPLY	LAB SUPPLY	EXTERNAL BATTERIES	EXTERNAL BATTERIES	BA386	BA386	BA386	
Transmitter Serial No.	11345	11345	11345	11339	11333	11339	11339	
Receiver Serial No.	11325	11325	11325	11333	11339	11333	11333	
Transmitting Frequency	33.05	33.05	33.05	33.05	33.05	33.05	33.05	
Test Date	10/10/67	10/11/67	10/13/67	10/13/67	10/19/67	11/6/67	11/6/67	

In These Frequency Ranges (MHz)	Number of Unusable Channels					Number of Unusable Channels From Chart
	Test 1	Test 2	Test 3	Test 4	Test 5	
53-54	0	7	6	—	—	0
54-55	0	4	4	—	—	0
55-56	0	9	2	—	—	1
56-57	6	6	2	—	—	2
57-58	1	4	2	—	—	0
58-59	0	3	2	—	—	0
59-60	0	0	0	—	—	0
60-61	1	1	0	—	—	0
61-62	1	3	0	—	—	0
62-63	1	2	0	—	—	0
63-64	1	3	0	—	—	0
64-65	0	5	1	2	1	0
65-66	0	7	6	10	0	1
66-67	4	11	4	—	—	1
67-68	4	20	7	—	—	2
68-69	3	5	2	—	—	0
69-70	1	4	0	—	—	0
70-71	0	4	0	—	—	0
71-72	0	1	0	—	—	0
72-73	2	3	0	—	—	0
73-74	0	1	0	6	6	0
74-75	1	1	0	—	—	0
75-76	0	6	0	—	—	0
Separation	4'	10'	20'	20'	20'	
Antenna Size	3'	10'	10'	10'	10'	
Location	LAB	LAB	OUTSIDE	OUTSIDE	OUTSIDE	
Polarization	HOR	HOR	VERT	VERT	VERT	
Power Source	LAB SUPPLY	LAB SUPPLY	EXTERNAL BATTERIES	EXTERNAL BATTERIES	BA386	
Transmitter Serial No.	11345	11345	11345	11339	11333	
Receiver Serial No.	11325	11325	11325	11333	11339	
Transmitting Frequency	33.05	33.05	33.05	33.05	33.05	
Test Date	10/10/67	10/11/67	10/13/67	10/13/67	10/19/67	

fact, causing this RF interference was determined by noting the signal quieting when the transmitter was turned on and off.

It can be seen from Table 5-1 that a very large number of unusable frequencies were found, in some cases as many as twenty per megacycle. In Test 4, for instance, more than half the frequencies between 30 and 51 MHz were found to be unusable (236 channels out of a total of 420). The last column in Table 5-1 shows the number of unusable frequencies specified by the charts in the Technical Manual. Only 14 channels are identified in this frequency interval by the charts.

It was noted during these tests that the cables of the hand set and batteries (when used) acted as excellent antennas for spurious frequencies. On one occasion, it was found that proximity of the hand set cable to the battery cables would cause feedback within a single unit.

5.2 FREE-FLOATING BALLOON RADIO RELAY PLATFORM

5.2.1 Summary

An estimate of on-station time for free balloon systems and a design study of a simple balloon relay platform are presented in the following paragraphs.

The results of an examination of Vietnam wind statistics to determine time on station per balloon platform are discussed in order to estimate mission hardware quantity requirements. Since on-station time is a parameter independent of balloon size (payload weight), a total quantity of platforms required per operation (or per battalion, or per theater), must be determined on the basis of tactical deployment. Whatever tactical deployment arrangement is selected then identifies the number of relay channels required, thus fixing payload weight.

Vietnam wind statistics indicate a minimum wind layer normally exists over Vietnam in winter and spring at 60,000 to 80,000 feet, which may provide favorable station holding for a free-floating platform. This minimum wind layer is replaced by unfavorable easterly currents in summer and autumn.

Available wind data appear adequate to approximate hardware requirements and to determine system feasibility. However, better definition of the shear profile of the minimum wind layer, and average wind values over relatively short periods (three days to 12 hours) are desired for better assessment of balloon time on station performance and design sophistication.

A brief study has been conducted to determine the characteristic relationships of the principal components of an unsophisticated assembly capable of initiation on the ground to place a single free balloon and relay system in the air on station. The component characteristics have been developed parametrically to accommodate a range of payloads up to 1,000 pounds.

It appears that the free balloon may show promise as a relay platform if the maximum component weight is compatible with man's ability to assemble and handle a complete launch round without sophisticated support equipment.

5.2.2 Analysis of Time On Station

5.2.2.1 General. A free balloon in equilibrium (lift/weight = 1.0) is subject to the natural variations in air movement for its position with respect to time if velocity variations are small. In a minimum wind field a balloon could remain for a potentially long period over a fixed location on the ground. A summary of wind structure knowledge (Chapter 4 of Reference 1) and a specific look at minimum wind fields (Reference 2) indicate that in the region of 60,000 to 80,000 feet altitude, low wind velocities (0 - 15 knots) are general during certain seasons of the year. The upper and lower boundaries of this phenomenon are fundamentally extensions of the tropospheric westerlies and stratospheric easterlies and define a zone of transition between the two opposing currents of air. To determine economic feasibility of employing a balloon in this low velocity region requires a knowledge of the persistence and cross section of the minimum wind layer. For possible early application, Vietnam conditions were considered.

5.2.2.2 Wind Statistics. Early in the High Altitude Radio Relay (HARR) Study, assistance of the Meteorology Division, Department of the Air Force (SSSW, SSD) was enlisted in obtaining wind data of the Southeast Asia region. The specific request for information is quoted approximately as follows:

a. "Seasonal meridional cross sections to 100,000 feet altitude for the region from 100-110°E longitude between 5-25°N latitudes. Winds in excess of 20 knots need not be plotted."

b. "Monthly 50-, 70-, 90-, 95-, and 99-percent wind profiles for three stations: Saigon, South Vietnam; DaNang, South Vietnam; and Chiang Mai, Thailand. Seasonal profiles may be sufficient if the monthly variation is small."

Report 5655 (Reference 3) was issued by the Environmental Technical Center (ETAC) USAF in response to the above request. Wind statistics in Reference 3 were extracted and/or computed from Standard Rawinsonde Summary data for the respective stations. These summaries are considered the most reliable and least biased of the available sources of upper air wind statistics. Data for the levels surface through 300 to 200 mbs are considered adequate to provide a fairly stable wind distribution. Above 200 mbs, the source data are limited and provide only an estimate of the wind distribution.

Rawinsonde readings are normally obtained every 12 hours, and the Southeast Asia data encompasses a good record period of several hundred observations at each station, over a period of 4 years at DaNang to 11 years, with some gaps, at Saigon and Chiang Mai. Data is summarized at specific pressure levels from 850 to 20 millibars. The altitude span between these pressure level data points varies from 4,000 to 10,000 feet, except Saigon records show intermediate levels.

Seasonal meridional cross section charts in Reference 3 depict the east-west resultant wind speeds. A vertical null in the 10° to 15° latitude prevails through winter and spring seasons with a horizontal null or minimum wind layer between 70 and 30 millibars (61,000 to 78,000 feet). In summer and autumn seasons, the easterly flow dominates, with a minimum wind layer possible at lower altitudes (20,000 feet). Wind statistics and meridional cross sections for Vietnam were used to determine time on station for a balloon platform for various relay range (horizontal span) distances compatible with tactical requirements.

5.2.2.3 Relay Operational Geometry. The relay-to-terrain relationships developed for the effectiveness model (paragraph 4.5.4.1, Reference 4) of the HARR study, are applied to the balloon as constraints defining distance and time on station. The geometry is illustrated in Figure 5-1 showing various cone profiles as a function of coverage range on the ground and angular constraints due to terrain. The 50 nautical mile coverage circle (25 n.m. radius) provides full battalion communication range. The 25 n.m. coverage circle serves battalion to individual company communications. The 10 n.m. coverage circle serves company to platoon requirements. The 80° angular constraint represents a limit for relay transmission through heavy vegetation over flat terrain. The 35% constraint ($\cot^{-1}$ .35) is based on an average of maximum mountain slopes, representative of line-of-sight transmission from a point high enough to avoid "shadow zones." These conditions are explained in more detail in the tactical analysis of paragraph 4.5.4.1 of Reference 4.

The cone profiles of Figure 5-1 outline two intersecting cones; a coverage cone and a station cone. A relay positioned at the apex of the coverage cone will satisfy the coverage requirement if the relay is stationary at this point above the terrain, equidistant between transmitter and receiver station. Since a free balloon moves with the wind, its time on station is a function of its altitude above the apex (within the confines of the station cone) and the average wind velocity at that altitude. The ideal "on-station" path of the free balloon platform is represented by the diameter of the circle which represents the intersection of the station cone and an imaginary plane at balloon platform is represented by the diameter of the circle which represents the intersection of the station cone and an imaginary plane at balloon flotation altitude.

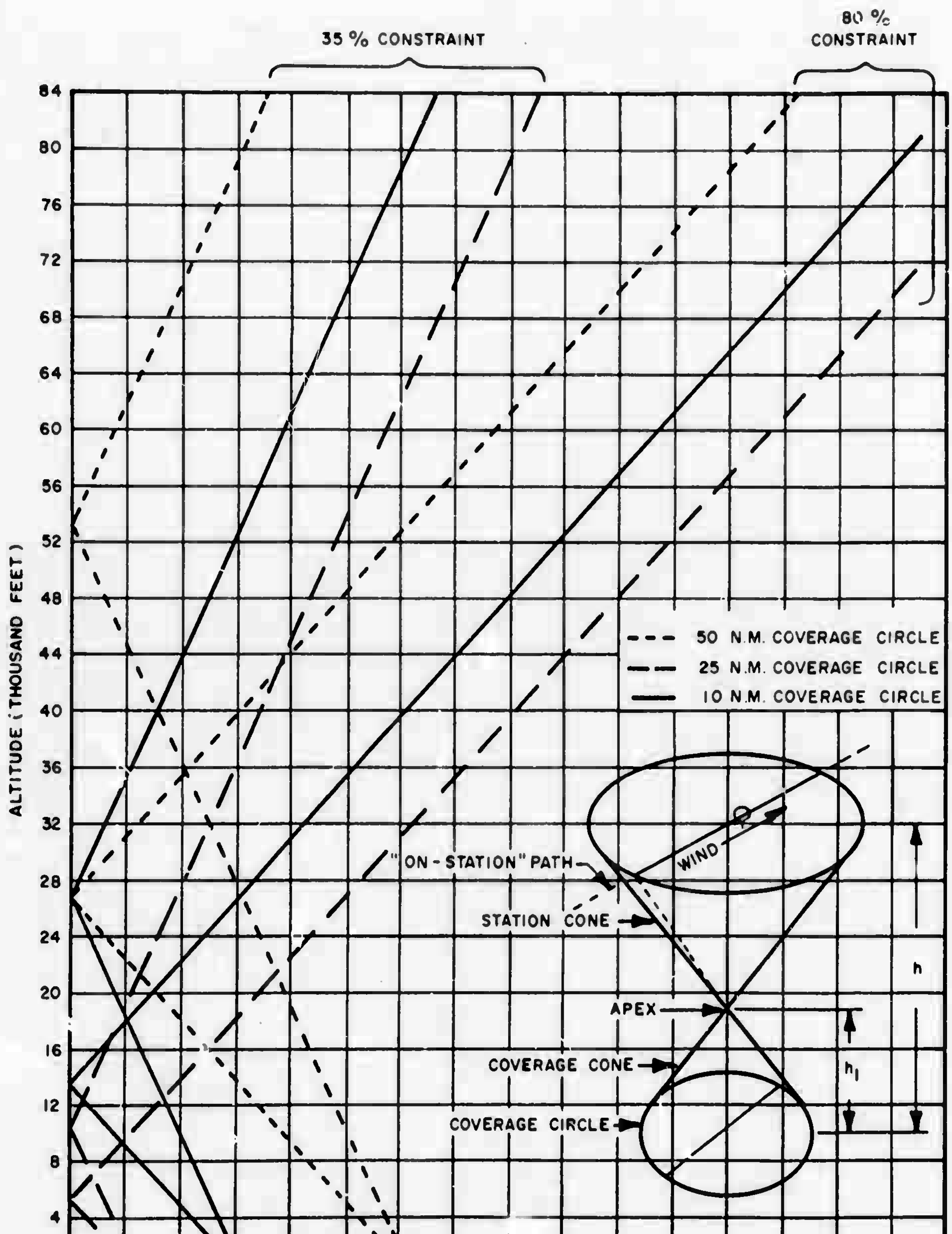


Figure 5-1. Platform Placement - Cone Profiles

5.2.2.4 <u>On-Station Estimates</u>. By relating tactical geometry of paragraph 2.3 to the wind statistics of Reference 3, on-station estimates were determined. Table 5-2 presents results using Saigon wind statistics; Table 5-3, DaNang; and Table 5-4, Chaing Mai. These tables contain the resultant wind direction (direction from which the wind blows) and the resultant wind speed from that direction. On-station distances are listed for a 25 nautical mile coverage circle. For a 50 nautical mile coverage circle, the listed on-station distance should be reduced by 25 nautical miles; and for a 10 nautical mile coverage circle, the listed value should be increased by 15 nautical miles. Figure 5-1 shows that a reduction of coverage lowers the apex and increases the station circle to coverage circle ratio.

On-station distance (d_s) is determined by the following equation:

$$d_s = \frac{d_c}{h_1} (h - h_1)$$

where,

d_s = on-station circle diameter (nautical miles)

h = platform (relay) altitude (feet)

h_1 = height of coverage cone apex (feet)

d_c = coverage circle diameter (nautical miles)

The equation for on-station time is:

$$t_s = \frac{d_s}{\bar{v}_w}$$

where,

t_s = time on station (hours)

$\bar{v}_w$ = mean wind speed (knots)

In Table 5-2, the resultant wind direction shows a reversal from easterly to westerly near the 70 mb (61,000 foot) level and another reversal back

Table 5-2 - Saigon Seasonal Wind Statistics and On-Station Estimates for Free Balloon Platform

Season	Altitude (feet)	Press (mbs)	Wind Direction (degrees)*	Wind Speed (knots)	80° Constraint Cond. On-Station Estimated Distance (n.miles)	Time (hours)	35% Constraint Cond. On-Station Estimated Distance (n.miles)	Time (hours)
	58629	80	111	5.0	84.4	16.9	30.1	6.0
	61047	70	232	1.8	89.0	49.5	32.4	18.0
	64177	60	239	1.9	96.6	50.8	35.3	18.6
Winter	67697	50	272	4.9	101.3	22.5	38.6	8.6
	72333	40	085	12.1	110.0	9.1	43.0	3.6
	78186	30	079	12.8	121.0	9.5	48.5	3.8
	86827	20	087	24.1	137.0	5.7	56.7	2.4
	101978	10	086	17.4	165.4	9.5	70.8	4.1
	61047	70	091	5.2	89.0	17.12	32.4	6.23
	64177	60	092	7.2	96.6	13.42	35.3	4.90
Spring	67697	50	230	1.2	101.3	84.50	38.6	32.20
	82333	40	090	19.0	110.0	5.79	43.0	2.26
	78186	30	088	14.0	121.0	8.64	48.5	3.47
	14429	600	263	7.7	1.9	0.25	—	—
	19190	500	216	2.1	10.8	5.14	—	—
	24829	400	097	4.4	21.3	4.85	—	—
	31742	300	085	38.5	34.2	0.89	4.8	0.12
Summer	61047	70	086	33.2	89.0	2.68	32.4	0.98
	64177	60	088	37.2	96.6	2.60	35.3	0.95
	67697	50	088	34.1	101.3	2.97	38.6	1.13
	14429	600	089	4.0	1.9	0.48	—	—
	19190	500	090	5.8	10.8	1.86	—	—
	24829	400	087	8.0	21.4	2.68	—	—
	31742	300	081	10.8	34.2	3.17	4.8	0.44
Autumn	35919	250	080	12.4	42.0	3.39	8.8	0.71
	40768	200	084	16.8	51.0	3.03	13.3	0.79
	46647	150	087	25.1	62.0	2.47	18.9	0.75
	54436	100	091	28.5	76.6	2.69	26.2	0.92
	58629	80	090	21.2	84.4	3.98	30.1	1.42
	61047	70	090	18.3	89.0	4.86	32.4	1.71
	64177	60	086	14.5	96.6	6.66	35.3	2.43
	67697	50	085	17.0	101.3	5.96	38.6	2.27
	72333	40	086	18.0	110.0	6.10	43.0	2.39

NOTE: Above on-station estimates are calculated for 25 n. mile coverage circle.

* Direction from which the wind blows; degrees from north (clockwise on map)

Table 5-3 - Da Nang Seasonal Wind Statistics and On-Station Estimates
for Free Balloon Platform

Season	Altitude (feet)	Press (mbs)	Wind Direction (degrees)	Wind Speed (knots)	80° Constraint Cond. On-Station Distance (n.miles)	80° Constraint Cond. Estimated Time (hours)	35% Constraint Cond. On-Station Distance (n.miles)	35% Constraint Cond. Estimated Time (hours)
Winter	54383	100	246	11.8	76.4	6.5	26.1	2.21
	61106	70	256	7.3	89.0	12.2	32.4	4.44
	67789	50	252	5.0	102.3	20.2	38.7	7.74
	78297	30	093	8.6	121.0	14.1	48.6	5.65
	86857	20	090	13.4	137.0	10.2	56.5	4.22
	102028	10	088	12.5	165.3	13.2	70.8	5.66
Spring	35899	250	263	12.5	39.1	3.1	8.7	0.70
	40741	200	257	14.2	51.0	3.6	13.3	0.94
	46624	150	245	9.2	62.0	6.7	18.9	2.05
	54383	100	078	3.7	76.4	20.6	26.1	7.06
	61106	70	093	5.6	89.0	15.9	32.4	5.79
	67789	50	089	5.9	102.3	17.3	38.7	6.57
	78297	30	088	15.4	121.0	7.8	48.6	3.16
	86857	20	089	19.0	137.1	7.2	56.7	2.99
Summer	14413	600	233	4.3	1.9	0.44	—	—
	19193	500	177	2.4	10.8	4.50	—	—
	24833	400	100	4.2	21.3	5.08	—	—
	31742	300	079	9.5	34.2	3.60	4.8	0.50
	35899	250	074	13.7	39.1	2.86	8.7	0.63
	61106	70	085	38.6	89.0	2.30	32.4	0.84
	67789	50	088	34.8	102.3	2.94	38.7	1.11
	78297	30	090	41.7	121.0	2.90	48.6	1.17
Autumn	14413	600	081	5.0	1.9	0.38	—	—
	19193	500	089	5.6	10.8	1.93	—	—
	24833	400	087	5.5	21.3	3.87	—	—
	31742	300	078	4.9	34.2	6.98	4.8	0.99
	35899	250	055	2.9	39.1	13.50	8.7	3.00
	40741	200	087	7.0	51.0	7.28	13.3	1.90
	46624	150	095	11.8	62.0	5.25	18.9	1.60
	54383	100	091	20.8	76.4	3.67	26.1	1.25
	61106	70	090	19.2	89.0	4.64	32.4	1.69
	67789	50	090	18.3	102.3	5.60	38.7	2.12
	78297	30	090	25.7	121.0	4.71	48.6	1.89
	86857	20	090	44.5	137.1	3.08	56.7	1.27

See note on Table 5-2

Table 5-4 Chiang Mai Seasonal Wind Statistics and On-Station Estimates for Free Balloon Platform

Season	Altitude (feet)	Press (mbs)	Wind Direction (degrees)	Wind Speed (knots)	80° Constraint Cond. On-Station Distance (n.miles)	Estimated Time (hours)	35% Constraint Cond. On-Station Distance (n.miles)	Estimated Time (hours)
Winter	61165	70	267	13.9	89.2	6.4	32.5	2.34
	67667	50	274	8.7	101.5	11.7	38.6	4.44
	78363	30	090	6.7	121.2	18.1	48.6	7.26
	86991	20	086	12.0	137.5	11.5	56.6	4.71
Spring	54318	100	255	9.1	76.3	8.4	26.0	2.86
	61165	70	271	1.4	89.2	63.8	32.5	23.20
	67667	50	071	5.3	101.5	19.2	38.6	7.30
	78363	30	118	10.3	121.2	11.8	48.6	4.72
	86991	20	086	12.6	137.5	10.9	56.6	4.49
Summer	14373	600	259	4.5	1.8	0.40	—	—
	19163	500	205	1.1	10.7	9.79	—	—
	24793	400	086	5.8	21.3	3.67	—	—
	31683	300	077	14.9	34.1	2.29	4.8	0.32
	40686	200	075	29.6	51.0	1.72	13.2	0.45
	46578	150	075	40.0	62.0	1.55	18.8	0.47
	54318	100	080	51.9	76.3	1.47	26.0	0.50
	61165	70	087	45.6	89.2	1.96	32.5	0.71
	67667	50	087	44.4	101.5	2.29	38.6	0.87
	78363	30	090	48.0	121.2	2.53	48.6	1.01
	86991	20	092	52.3	137.5	2.63	56.6	1.08
Autumn	14373	600	223	1.0	1.8	1.80	—	—
	19163	500	222	1.5	10.7	7.15	—	—
	24793	400	230	2.2	21.3	9.68	—	—
	31683	300	257	3.6	34.1	9.48	4.8	1.33
	40686	200	258	5.1	51.0	10.00	13.2	2.59
	46578	150	180	2.4	62.0	25.80	18.8	7.83
	54318	100	094	11.8	76.3	6.46	26.0	2.20
	61165	70	094	12.6	89.2	7.08	32.5	2.58
	67667	50	091	19.2	101.5	5.30	38.6	2.01
	78363	30	095	27.4	121.2	4.43	48.6	1.76
	86991	20	096	27.0	137.5	5.10	56.6	2.10

See note on Table 5-2

to easterly near the 40 mb (72,000 feet) level at Saigon in winter. Similar conditions are indicated in the other tables and at other seasons. The regions of wind reversal are of particular interest since they denote a static layer of air in which a balloon may remain relatively stationary for a prolonged period of time.

A more descriptive presentation results when on-station time is plotted as a function of altitude using values from the preceding tables. Figures 5-2, 5-3, 5-4, and 5-5 show the variation of on-station time for the measured Southeast Asia wind data during each season based on a 25 nautical mile coverage circle and an 80° station cone (flat terrain). Measured points are indicated. The curves are faired between points except where wind reversal is indicated by a projection toward an infinite on-station time. In Figure 5-2, the measured points for Saigon show a resultant wind change of 17 knots in approximately 5,000 feet of altitude, indicating that altitude control may be a sensitive factor in balloon platform design. Saigon data was taken at smaller altitude increments than the other stations, and it is likely that a sharp transition may exist at all stations.

The spring and autumn seasons (Figures 5-3 and 5-5) show a wide difference of maximum on-station time altitudes between data stations. The summer season (Figure 5-4) shows long on-station times are likely only near the 22,000 foot level.

On-station times for the 35% constraint (mountainous terrain) conditions are from 1/3 to 1/2 the 80° condition, indicating requirements for number of platforms for mountainous terrain will be two to three times the flat terrain requirement.

5.2.2.5 Discussion of Balloon On-Station Requirements. A balloon platform capable of holding a constant altitude will remain on station for many hours in the minimum wind field during winter and spring seasons. An estimate of the number of balloon systems required may be made for a specific case as follows:

Assume:

a. Balloon on-station altitude (h) = 68,500 feet.
b. Saigon, flat terrain (See Figure 5-2).
c. Battery life limits on-station time to 70 hours maximum.
d. Relay required continuously on station (day and night).
e. Eighty-five percent of ideal on-station path is average due to launch accuracy and reliability of performance.

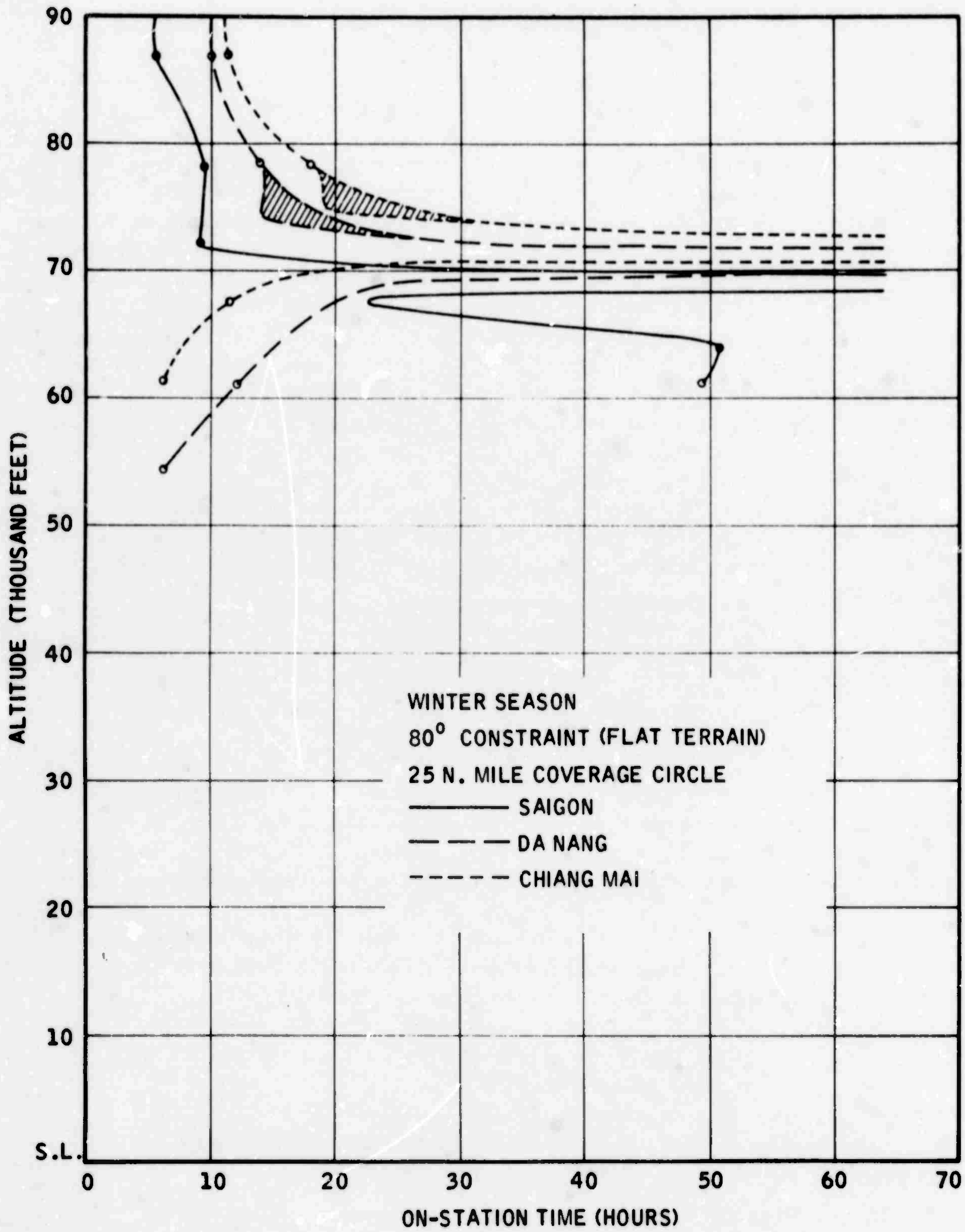


Figure 5-2. Estimate of Free Balloon "On Station" Time vs Altitude, at Three Southeast Asia Locations During Winter, Over Flat Terrain

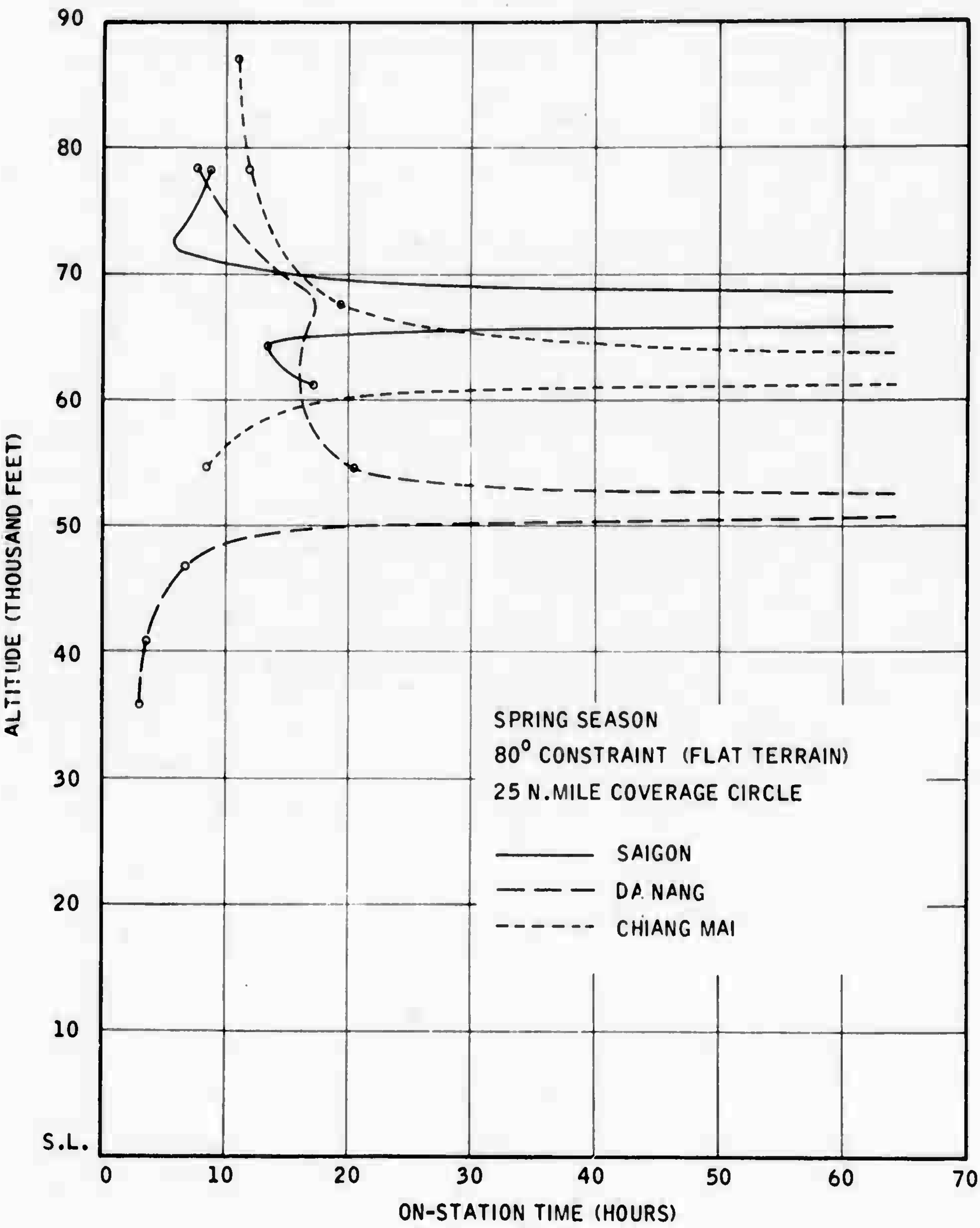


Figure 5-3. Estimate of Free Balloon "On Station" Time vs Altitude At Three Southeast Asia Locations During Spring Over Flat Terrain

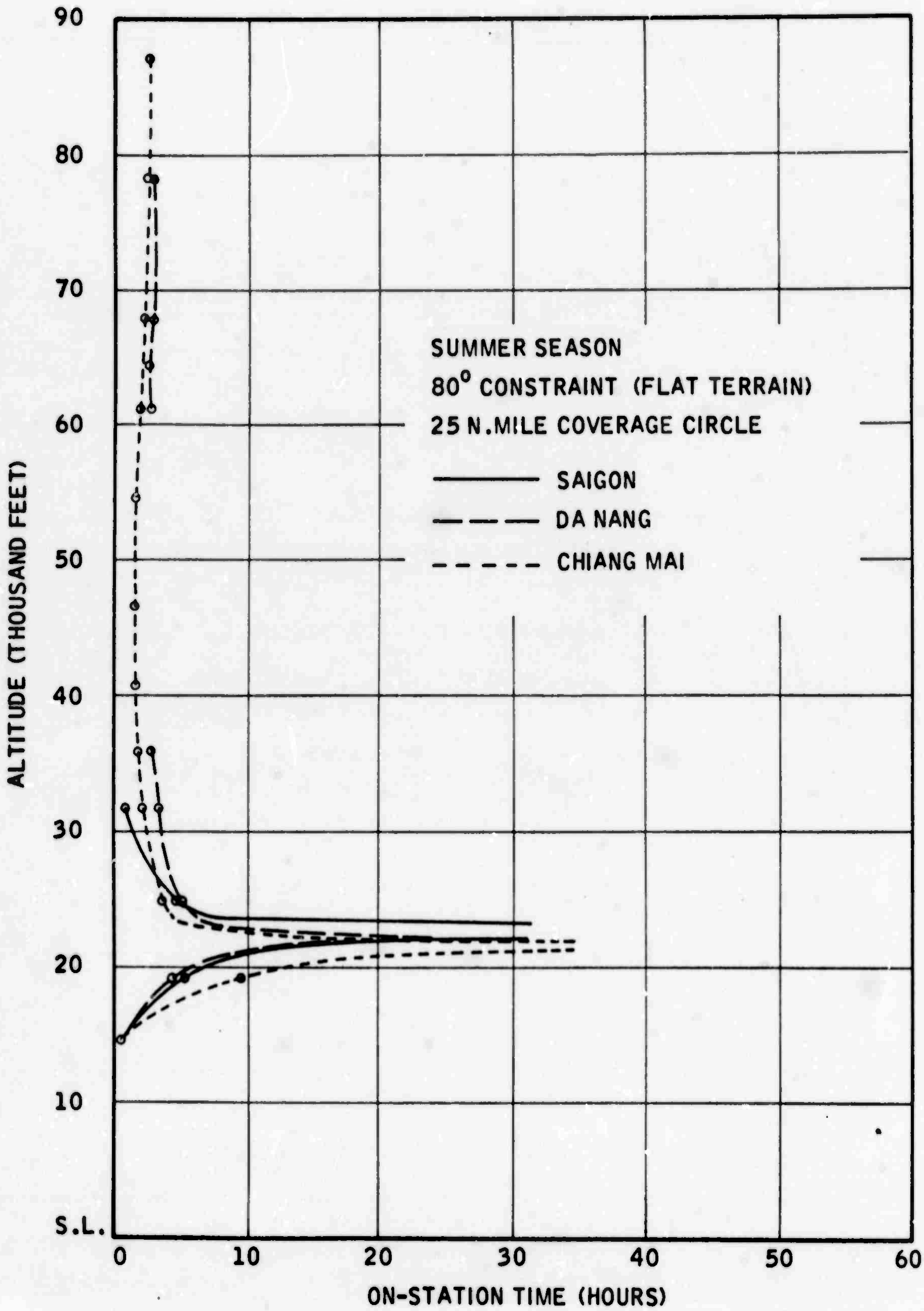


Figure 5-4. Estimate of Free Balloon "On Station" Time vs Altitude, at Three Southeast Asia Locations During Summer Over Flat Terrain

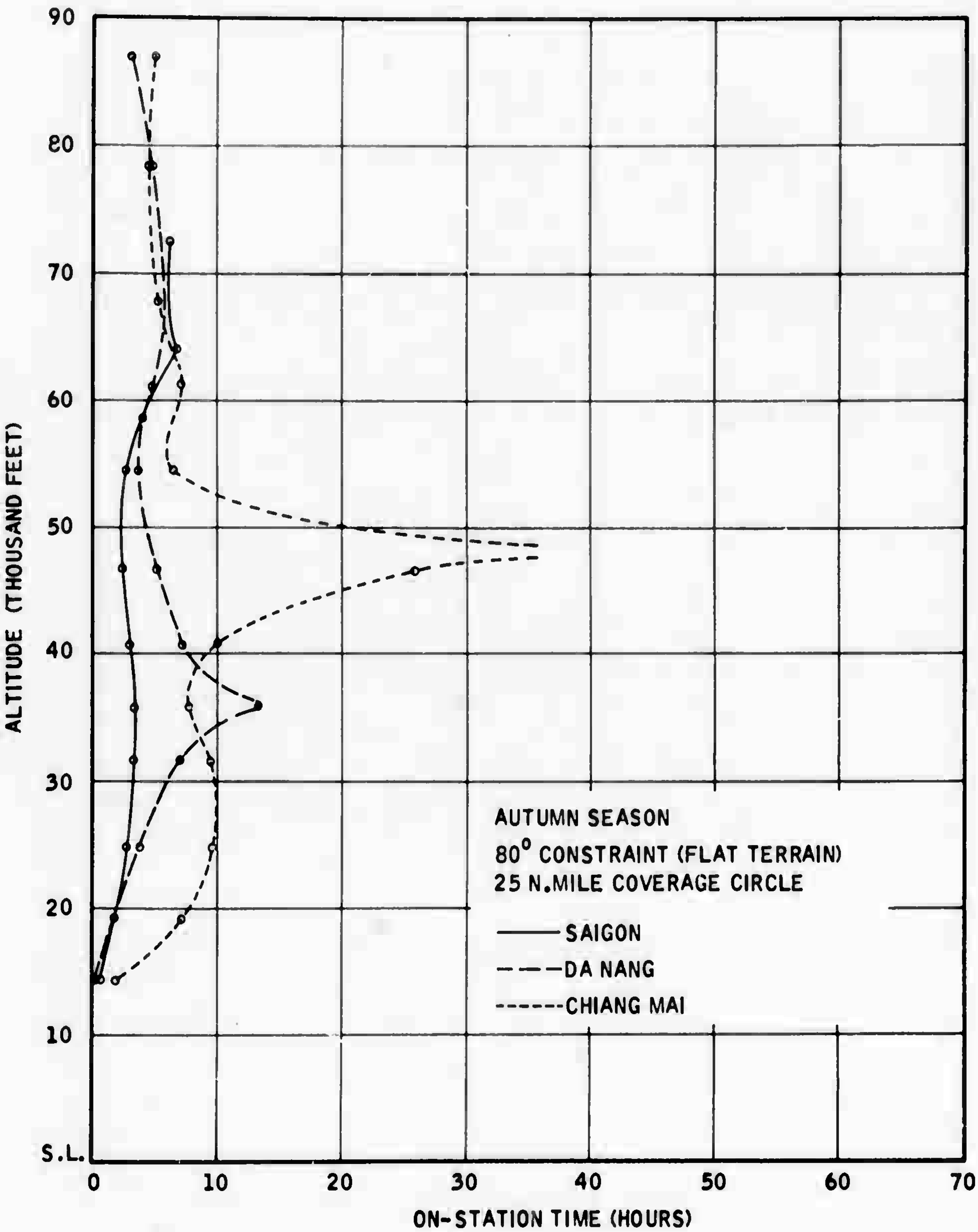


Figure 5-5. Estimate of Free Balloon "On Station" Time vs Altitude, at Three Southeast Asia Locations During Autumn, Over Flat Terrain

Then, the number of balloon systems per day

$$N = 0.403 \text{ per day in winter } (t_s = 70 \text{ from Figure 5-2})$$
$$= 0.403 \text{ per day in spring } (t_s = 70 \text{ from Figure 5-3})$$
$$= 9.41 \text{ per day in summer } (t_s = 3.0 \text{ from Figure 5-4})$$
$$= 4.70 \text{ per day in autumn } (t_s = 6.0 \text{ from Figure 5-5})$$

Thus, a year's requirement total 1,357 systems for a continuous single relay station.

A similar determination of requirements at DaNang with mountainous conditions, balloon height = 70,500 feet, gives a year's requirements total of 4,100 systems for a continuous single relay station.

The foregoing provides a methodology for estimating platform quantity requirements when tactical application, number of channels, mission duration, and support requirements are defined.

5.2.3 Balloon System Description

5.2.3.1 Introduction. A suggested balloon system of minimum sophistication consists of a superpressure envelope structure of natural shape, filled with helium gas which supports a cylindrical payload with a limp wire antenna suspended below it. This basic platform and relay assembly properly packaged is propelled from the ground toward station position by a solid propellant rocket motor which separates from the remainder of the launch round at a selected point along the trajectory, deploying the balloon in the manner of a streaming parachute; the spent motor falling free on its own trajectory to the ground. During deployment, helium gas stored at 5,000 psi in a reservoir in the forward end of the round is fed at a controlled rate through a valve and feed line to the balloon envelope directly behind the relay assembly. When the balloon is fully inflated, the valve is sealed to prevent escape of helium from the balloon and the forward portion of the launch round separates and falls to the ground as the balloon and energized relay with antenna extended seek an equilibrium station altitude. A sequence of the above described events is depicted in Figure 5-6.

A launch round is defined as a complete vehicle, launched from the ground to place a balloon platform and relay system on station. It includes the following major components:

Balloon	Gas reservoir
Inflation gas	Booster motor
Payload	Control hardware

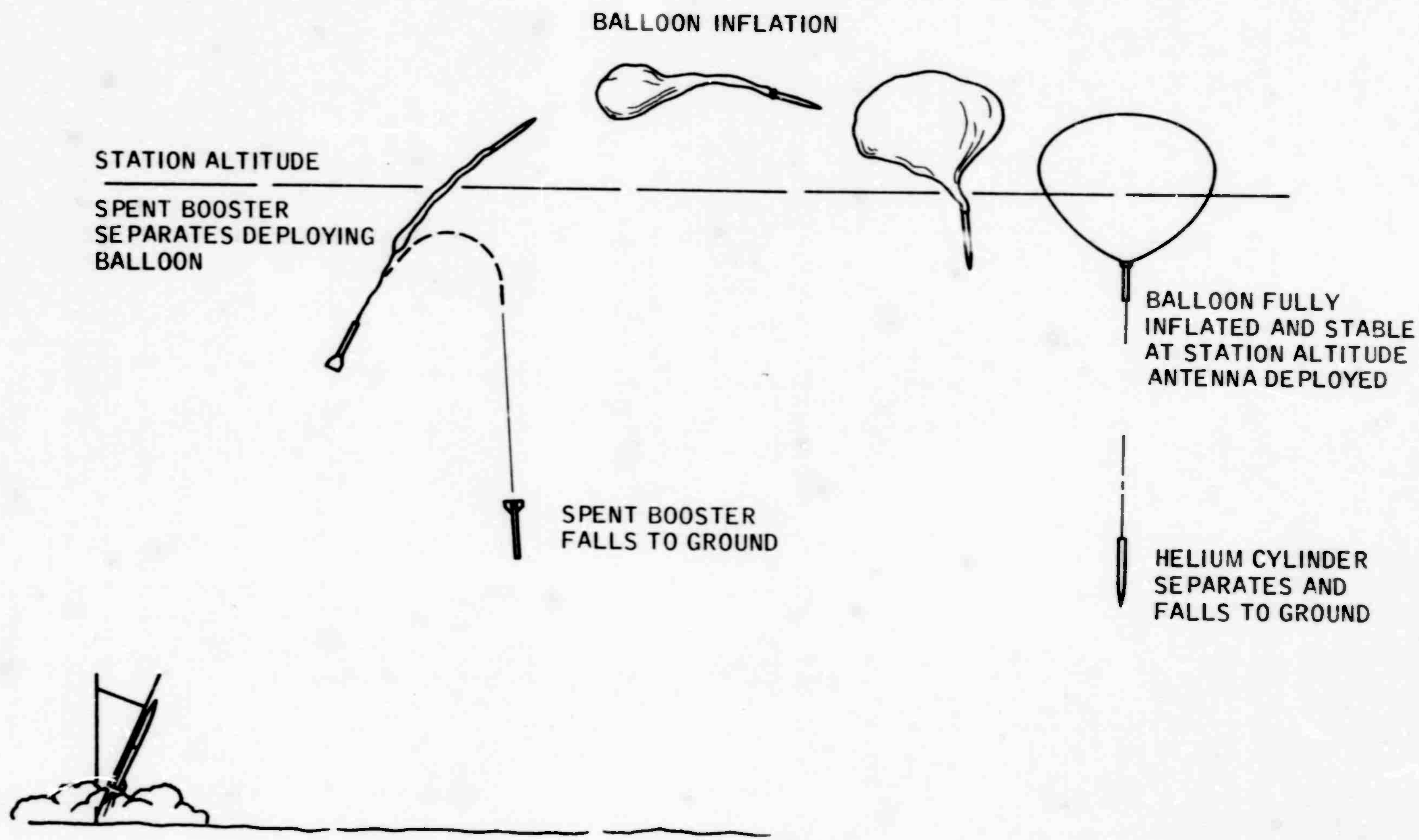


Figure 5-6. Balloon Launch, Deployment and Inflation Sequence

The payload weight determines the balloon size. The lifting gas storage reservoir size is then determined by the balloon size. The combined weight of balloon, gas reservoir, and payload then determine the size of the booster motor.

A preliminary investigation is presented of the characteristic relationships of these major components using 70,000 feet as a representative station altitude. Figure 5-7 shows an arrangement of the major components comprising a typical launch round. The features, dimensions, and relative weights are discussed in the following paragraphs.

5.2.3.2 Balloon Design. For reasons of material weight and strength efficiency, a natural-shaped balloon is considered a likely choice for the relay platform. This is the shape that the balloon achieves at float altitude if circumferential stress is zero. The contour can be accurately determined as a function of balloon material weight and payload weight. References 5, 6a, and 8b provide extensive background on balloon shape technology.

Employing the natural shape design, a superpressure is provided by a 15 percent over-supply of lifting gas arbitrarily selected to compensate for thermal variations and gas leakage over a maximum station period.

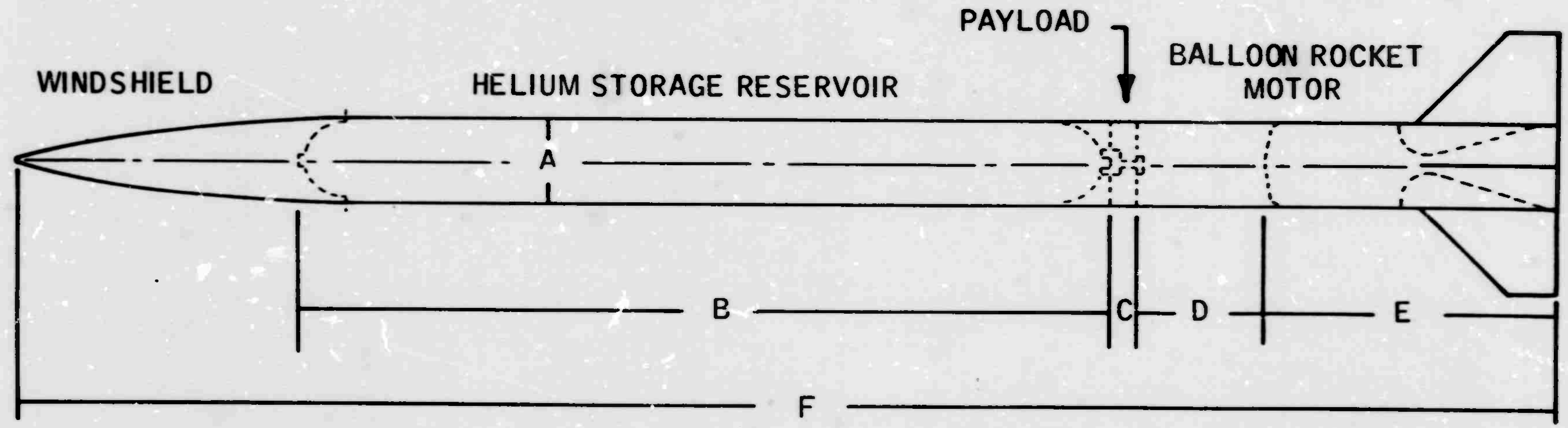
To maintain a nearly constant volume under the effects of overpressure calls for a strong material with low expansion characteristics. A Mylar film reinforced with Dacron scrim has been selected for the balloon material in this study which has a weight of 0.0055 pounds per square foot. Development of thin Mylar films laminated with 220 denier Dacron leno weave with its adhesive are described in References 6b, 7b, and 8a.

For equilibrium conditions at 70,000 feet altitude, the gross load must equal the gross lift. Gross lift is the difference in the weights of displaced air and an equivalent volume of the lifting gas at equal pressure and temperature. Gross load is the sum of the weights of the balloon, lifting gas, and the payload.

Figure 5-8 shows the variation of gross load, balloon weight, and lifting gas weight with payload where helium is the lifting gas and balloon material is Mylar film reinforced with Dacron scrim at 0.0055 lb/ft^2 plus 5% seam allowance.

5.2.3.3 Lifting Gas. Although Hydrogen shows advantages in weight and possibly overall cost, Helium is considered the likely choice of lifting gas for reasons of safety and reliability. An inert gas is preferred in the proximity of pyrotechnic actuators and rocket boosters.

5.2.3.4 Gas Storage Reservoir. Gas storage vessels are produced from mild steel at relatively low cost. More efficient in terms of weight and size are vessels of carbon steel, monofilament wound glass fibers, and titanium. Shapes vary from long cylindrical to a sphere. The sphere is more efficient in terms of contained volume per unit weight of vessel. However, the gas container represents such a large percentage of the launch round that a sphere is not compatible with a



BALLOON DIAMETER	A	B	C	D	E	F	PAYLOAD
25 FT	8.6	58.0	2.27	6.5	28.21	124.98	9.0 LBS
27 FT	9.5	66.1	2.55	6.6	29.15	137.70	12.4 LBS
30 FT	10.2	76.7	3.38	7.0	33.06	155.84	18.9 LBS
35 FT	11.2	100.0	4.83	7.9	38.08	189.94	32.7 LBS
42 FT	12.9	123.0	6.83	9.5	44.18	228.49	61.5 LBS
50 FT	15.1	152.0	9.44	7.8	53.34	275.51	113.7 LBS
60 FT	17.8	186.0	11.68	9.0	62.24	331.23	198.7 LBS
70 FT	20.0	228.0	15.00	10.1	72.19	395.19	323.1 LBS
80 FT	21.8	251.0	19.16	11.1	78.06	435.32	490.4 LBS
90 FT	23.0	307.0	28.80	12.2	86.23	514.73	823.5 LBS
100 FT	24.0	412.0	32.20	14.2	90.43	622.83	1003.0 LBS

DIMENSIONS IN INCHES UNLESS OTHERWISE NOTED

Figure 5-7. Launch Round Dimensions - Free Balloon System

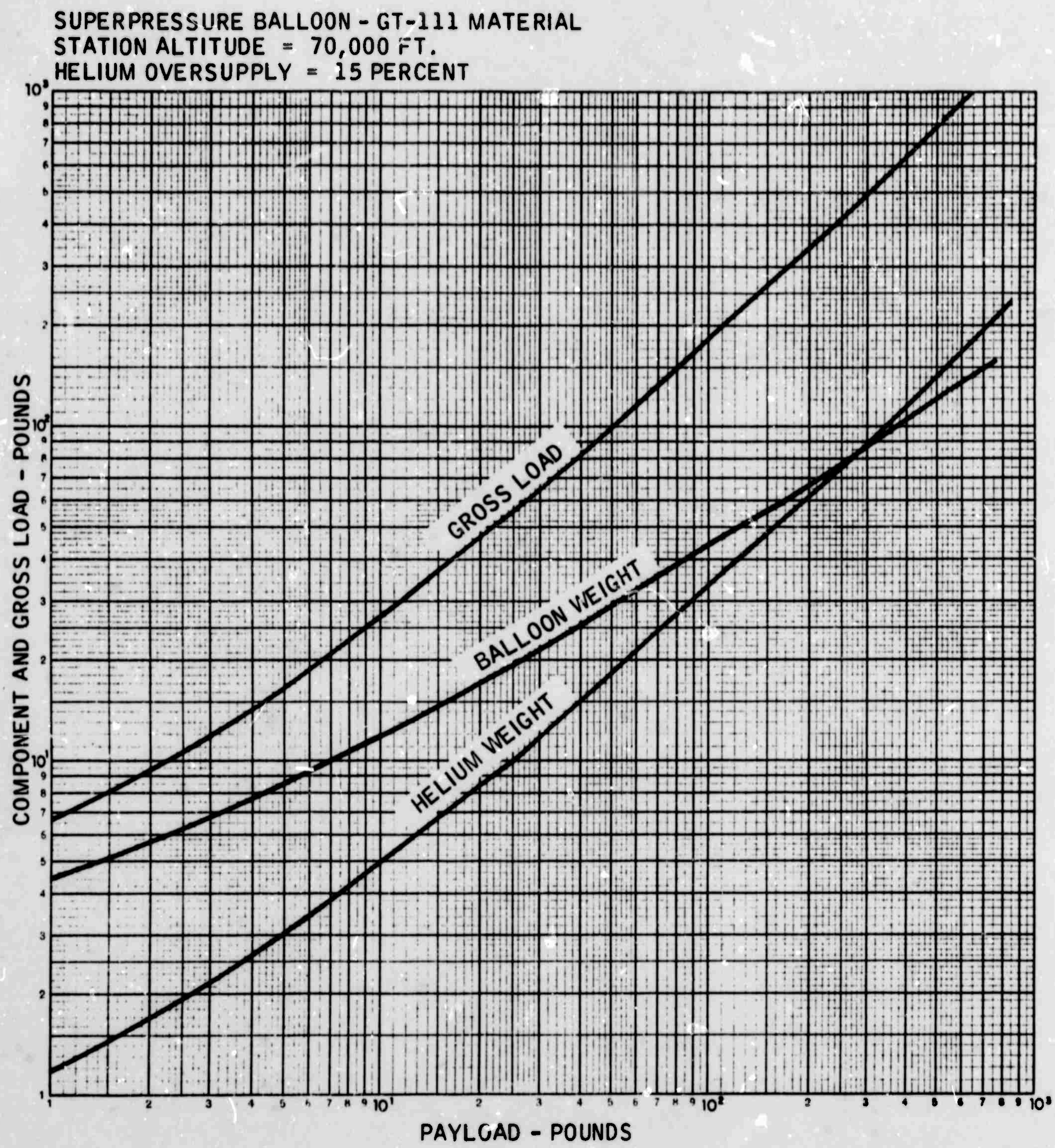


Figure 5-8. Gross Load, Balloon Weight and Helium Weight vs Payload

slender, low drag flight vehicle. A composite high strength steel cylinder with hemisphere ends employing monofilament glass fibers wound under tension around the cylindrical length has proven feasible for similar applications. In production quantities the cost of the sophisticated composite vessel is expected to result in a total launch round cost which is competitive with one employing a low cost, but heavy mild steel storage vessel. Reference 7a reports an analysis of the weight and cost relationship of the composite, high-strength steel, and mild steel bottles for an air-launched balloon application. The benefit of a minimum weight gas storage vessel will be more pronounced in the ground launched round cost.

Titanium bottles appear to possess even greater potential benefit for this application because of their high strength to weight factor. However, insufficient data are available to establish a weight and cost relationship at this time.

A review of available data shows that the composite vessel provides a higher efficiency than the glass sphere. A convenient index for comparison of types is the ratio of bottle weight to weight of stored helium. This index accounts for vessel design pressure and slenderness ratio among the variables. An index of 12.5 applies to an unslender composite cylinder designed for 5,000 psi internal pressure, whereas an index of 20 is characteristic of glass wound spheres. Conventional steel cylinders designed for 3,000 psi have an index of 30 - 30. An index of 12.7 has been used in estimating bottle weight representative of a slender, 5,000 psi storage cylinder.

5.2.3.5 Booster Motor. The slenderness ratio of the total launch round is determined largely by the gas storage cylinder. The objective has been to provide a length to diameter ratio for the total round of 15 or more, typical of efficient sounding rocket design. The booster weight parameter has been determined by the required weight to be boosted and the diameter of the helium bottle. Booster motor length then provides for propellant and nozzle requirements at a predetermined diameter as a function of the helium bottle size. Booster design has involved an approximation process for a common end burning propellant composition and its performance. There has been no attempt to optimize the rocket characteristics, although a refined analysis would consider changes in propellant to fast burning grains, particularly in the large sizes for maximum performance efficiency.

5.2.3.6 Control Hardware. The total weight parameter is not greatly influenced by the control hardware. A principal item will be a timing device to (1) initiate separation of the booster motor from the remainder of the launch round, and (2) cause release of the helium storage bottle after the balloon has been fully inflated. Explosive bolts may be used for the separation actuation functions. These are functions which are well within current technology. The weight and cost factors have been assumed to be a part of the inflation subsystem for purposes of this analysis.

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13. ABSTRACT

This is the final report on work performed under the High Altitude Radio Relay (HARR) study contract. The HARR program was an applied research study effort in support of the Advanced Research Projects Agency requirements for ~~Remote Area~~ Conflict ~~communications (Project AGILE)~~. The theoretical and analytical investigations were aimed at determining the key characteristics and parameters of systems to enable the use of military communications equipment over difficult paths.

The operational parameters considered were traffic, transmission range, terrain, foliage, frequency range, modulation, and types of relay capabilities. Equipment parameters were: relay control, transmission modes, size and weight, radio frequency power levels, receiver sensitivities, power requirements, operational life, interference, jamming, platform performance, platform payloads, compatibility, basing, availability, and costs.

The study was broken into four tasks: communication mission requirements, propagation analysis, relay analysis, and platform analysis.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Remote Area Conflict Communications						
Jungle Radio Propagation						
Tactical Radio Equipment for Relay						
Tactical Radio Relay						
Aircraft Platform for Relay						
Balloon Platforms for Relay						
Helicopter Platforms for Relay						
Aircraft Cost-effectivness Studies						
Tactical Communications Missions						